RADON ALERT

High School
General Academic Unit

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A resource manual and series of lesson plans on radon intended for classes in general science, social studies, home economics, and home repair/shop in the high schools in New Jersey.

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I. INTRODUCTION TO TEACHERS

To many people, radiation is something associated with a late-night news story about a nuclear power plant or weapons manufacturing. To the contrary, radiation plays an important role in diagnostic and therapeutic medicine, food preservation, and scientific research. Further, natural radiation is around us 24 hours a day, in the air we breathe, where we live, where we work, and where we play. The sun is a source of natural radiation and everyday geologic processes going on beneath our feet produce different radioactive elements. Worldwide, in some rocks and soils, a radioactive gas called radon is produced and escapes upward into the atmosphere. However, in certain instances this naturally occurring substance can escape from rocks and soils into our homes. In the home it can accumulate to high concentrations in the air we breathe, and this could be dangerous because radon is the second leading cause of lung cancer.

The topic of radon offers a superb opportunity to explore, in the classroom, the links between social studies, science, and language arts. Its social relevance helps to generate student interest. The enclosed activities focus on radon, an unseen, ubiquitous, and potentially dangerous radioactive phenomenon of nature, which is not well understood by the public.

Radon Alert contains a series of investigations and extension activities exploring radon and its potential impact on the citizens of New Jersey. The activities have been carefully integrated with the State of New Jersey Core Course Proficiencies for biology, earth science, chemistry/physics, and general academic course work. Each investigation emphasizes data gathering, graphing, and data analysis so that students are able to make inferences and draw conclusions about radon and its economic, political, social, and ethical consequences.

The data used in this teacher's guide represent the latest synthesized research from federal, state and local agencies. The teacher's guide itself includes an introduction to the topic and a collection of 10 lesson plans and numerous extension activities that will help you, the classroom teacher, integrate radon with any thematic area in science, math, social studies, home economics, or language arts. Although the major topics are scientific in nature, the lesson plans and activities have been carefully selected to be integrated into non-science coursework. An important objective of this program is to make science socially relevant and practical to the students. Companion teacher's guides focus more specifically on the core course proficiencies in biology, earth science, and chemistry/physics. The section Background Information on Radon (Section III) is fairly comprehensive and detailed. It is intended primarily for use by the teacher, as background information for the completion of the lesson plans.

The series of *Radon Alert* teacher's guides and lesson plans are targeted for classroom instruction at the elementary, junior high, and senior high school levels. All lesson plans take into consideration the broad range of student abilities and background information about radon. At the high school level, *Radon Alert* includes four separate instructional modules covering General Academic, Biology, Earth Science, and Chemistry/Physics. At the junior high level, the lesson plans are comprised of two modules: Science and General Academic. Since most elementary school classrooms are self-contained, the *Radon Alert* lesson plans for this level are comprised of a single document integrating science, mathematics, and whole language instruction.

Regardless of the instructional level, each lesson plan within *Radon Alert* represents a stand-alone activity. Although a specific sequence of lesson plans is recommended, the classroom teacher need not follow this approach. Each *Radon Alert* module includes a core group of activities that can be adapted to a wide range of ability levels and interests. These activities include: What do you think about radon? (survey), What is radioactivity?, What is radon?, What are radon risks?, and How can you control radon in your home?

The team that compiled this workbook hopes the enclosed investigations help to complement your curriculum by offering a set of experiments, surveys, and research data about a topic that is both relevant and practical for student exploration. Hopefully, you and your students will become better informed about this phenomenon of nature and by doing so alert others to one of the unseen risks that we face in our lives today.

MAJOR PROGRAM OBJECTIVES

Upon completion of the radon-based lesson plans and extended learning activities that follow, the students will be able to:

1. Identify the breakdown process called radioactivity
2. Consider the topic of radiation and the sources of radiation to the American public based on scientific data, rather than irrational fear
3. Identify three types of radiation: alpha, beta, gamma
4. Measure the half-life of radioactive elements
5. Select the most appropriate graph to display specific data
6. Identify how people are exposed to radon
7. Evaluate health risks from radon exposure and other common sources of risk

RADON PROJECT AND STATE SCIENCE PROFICIENCIES

II. CONTENT ALIGNMENT

GENERAL ACADEMIC

Radon Project	General Academic Proficiencies
1. Interpret charts and graphs that deal with: Radon characteristics Radioactive decay Risk communication	1. Interpret observations, graphs, and other data; comprehend the meaning of this information.
2. Formulate action plans to: Identify radon concentrations Mitigate radon problems Communicate risk	2. Evaluate data and make decisions based on sound scientific information and principles.

CHEMISTRY

Radon Project	Science Proficiencies
1. Atomic structure	1. Identify the components of the atom, i.e., location, charge, mass, name. Apply the knowledge of atomic structure to show its relationship to the chemical behavior of the elements.
2. Radon testing	2. Logically gather, order, and interpret data through an appropriate use of measurement and tools.
3. Radioactivity Types Measurements Radioactive decay series Example decay series - uranium	3. Describe the sources and effects of ultra-violet, gamma, alpha, beta, infra-red, and cosmic radiation.

PHYSICS

Radon Project	Science Proficiencies
1. Measurement variability and uncertainty	1. Recognize the error in measurement in light of their knowledge of the limits of precision in a given instrument and identify reasonable outcomes and predictions based on measurements with the instrument.
	2. Apply a problem-solving technique while conducting inquiries (e.g., formulating a problem, setting up experimental conditions, etc.).
	3. Apply the tools of physics in conducting inquiries (e.g., simple statistics, graphical models).

EARTH SCIENCE

Radon Project	Science Proficiencies
1. Geology Igneous rocks Metamorphism Sedimentary rocks	1. Explain how rocks are formed, changed, and interrelated in terms of the rock cycle.
2. General risk concepts and theory Radon - example of risk Statistics, probability Risk evaluation of radon relative to other risks Risk uncertainty Living with risk	2. Identify the risks, together with the appropriate actions, involved in dealing with natural phenomena and environmental hazards, including weather, earthquakes, volcanic activity, and radon.

BIOLOGY

Radon Project	Science Proficiencies
1. Lung anatomy and basic physiology	1. Identify the major systems of the human body and explain the major functions of each system.
2. How alpha particles damage cells: Cancer initiation Interactions between radon and cigarette smoking	2. Utilize the scientific method in solving biological problems and use mathematical operations where appropriate for solving these problems. Evaluate information about current biological issues.

PROBLEM: What is radon? Where does it come from? How does it get into my home? What are the health risks? What can I do about it?

III. BACKGROUND INFORMATION ON RADON

The United States Environmental Protection Agency (EPA) estimates that between 5,000 and 20,000 Americans die each year from lung cancer caused by indoor exposure to radon. In New Jersey, the State Department of Environmental Protection and Energy (DEPE) attributes about 500 cancer deaths per year to radon statewide. Exposure to radon in indoor air is second only to cigarette smoking as a cause of lung cancer in this country.

In recent years the State of New Jersey has spent over $3 million on a statewide scientific study of radon, evaluation of potential health effects, testing and remediation programs, and a public information program. Students and their families should know what the EPA and the state agencies have learned about radon, what the risks are, and what can be done to decrease possible health risks. This teacher's guide is intended to provide you with relevant and practical activities and investigations related to radon.

I. Radioactivity

In order to understand how radon is formed, how it disintegrates, and how it can damage lung tissue, we must first review some basic principles of atomic structure and radioactivity. The major components of an atom are protons, neutrons, and electrons. The solid mass of material at the center of the atom is called the nucleus. It is made up of protons and neutrons. Each proton has a single positive charge. Neutrons have no net charge. Orbiting around the nucleus at a very high speed are electrons. Each electron has a negative charge, and the number of negatively charged electrons will always equal the number of positively charged protons in a neutral or stable atom. The mass of each electron is negligible, well under one-thousandth of the mass of a proton or neutron. The bulk of the space taken up by the atom, however, is the empty space through which the electrons pass as they travel around the nucleus. Although the nucleus contains almost all of the atomic mass, it occupies almost none of the space. For example, if a typical atom was the size of Yankee Stadium, the nucleus would lie just behind second base and be about the size of a marble. The electrons would be flying around the rest of the stadium at very high speed.

The number of protons in an atom tells you what kind of element it is. This number is called the element's atomic number; it is designated by the symbol "Z". For example, hydrogen contains only one proton and has an atomic number of one (Z=1). Helium has two protons; carbon has 6, oxygen has 8, uranium has 92, radon has 86, and so on.

Nearly all of the mass of an atom is provided by its protons and neutrons, both located in the nucleus. The number of protons plus the number of neutrons is called the mass number, designated by the symbol "A". The mass number identifies the isotope of an element. Isotopes have the same number of protons (and therefore they are the same element), but they have different numbers of neutrons. For example, all radon isotopes have 86 protons (Z=86), but radon-222 has 136 neutrons (86 + 136 = 222), whereas radon-220 has only 134 neutrons (86 + 134 = 220). The chemical symbol for radon is Rn, and the mass number is usually placed either after the symbol (Rn-222) or to the left and above it (^{222}Rn). In either case, it simply designates the element radon, which always has 86 protons, and that the particular isotope of radon is the one with 136 neutrons. Different isotopes of the same element will behave exactly the same chemically, but they behave differently in terms of the nuclear reactions that they undergo.

Many isotopes of different elements are unstable. In other words, the protons and neutrons in their nuclei are not arranged in a stable configuration, and the nuclei are prone to spontaneous breakdown. During this process, called radioactivity, an unstable atom breaks down or disintegrates in an attempt to reach stability. When a nuclear disintegration or breakdown occurs, one or more particles or energy rays are emitted or given off and the nucleus changes as a result of this emission. Three types of radiation can be emitted: alpha, beta, and gamma.

- **Alpha** particles contain two protons and two neutrons. When a radioactive isotope such as radon-222 emits an alpha particle, it loses two of its protons and two of its neutrons, because they make up the alpha particle that flies out of the nucleus during the disintegration. Thus, when an alpha particle is emitted the atomic number of the isotope decreases by 2, and it becomes a new element. In the case of radon-222, the new element formed is called polonium-218. Also, the mass number decreases by 4. Alpha particles are very large by radiation standards, and they can do a lot of damage to sensitive biological tissue, mainly by knocking electrons off atoms. Although very damaging inside the body, they are easily stopped when they run into things, and cannot penetrate through skin or even pass through a piece of paper.

• **Beta** particles are high speed electrons that are ejected from a radioactive isotope at nearly the speed of light. They have medium penetrating power, and can penetrate a short distance into the body.

• **Gamma** rays constitute a form of high energy electromagnetic radiation, like visible light, but with more energy. Gamma rays are like x-rays, have great penetrating power, and can pass right through your body.

There are a number of radioactive decay chains that occur in nature. A decay chain is a series of radioactive isotopes that are produced in sequence by radioactive disintegrations. The decay chain of greatest interest with respect to the indoor radon problem is the one that proceeds from uranium-238 to eventually form lead-206. During the chain, a net total of ten protons are lost ($Z = 92$ for uranium and $Z = 82$ for lead) and the mass number is reduced by 32. Fourteen different isotopes are produced along the way, including radium-226, radon-222, and polonium-218. Eventually, lead-206 is formed, which is stable or non-radioactive, and the chain of decay is halted. All of the intermediate isotopes, called decay products (sometimes referred to as daughters or progeny), are radioactive or unstable. Some give off alpha radiation and some beta radiation. At some stages, gamma rays are also given off. Since lead-206 is not radioactive it remains lead-206 rather than changing into another element.

There is one additional property of radioactive decay that is important in examining radon issues, and that is known as the half-life. The half-life of an isotope is a reflection of how long it lasts, on average, before decaying into the next isotope in the chain. It is defined as the amount of time it takes for half of the material to undergo radioactive decay, and thereby disappear (be transformed into something else). The half-life of uranium-238 is 4.5 billion years. If you start with one gram (g) of ^{238}U and wait 4.5 billion years, only 1/2 g will be left. The other 1/2 g would have decayed into the next isotope in the chain. If you wait an additional 4.5 billion years, only 1/4 g of ^{238}U will be left (one-half of 1/2 g). Each of the decay product isotopes in the decay chain has its own half-life, and once it is formed it begins its decay to the next isotope in the sequence. The half-life of radon-222 is only 3.8 days. Some isotopes in the ^{238}U decay chain series have half-lives on the order of minutes, and for polonium-214 it is only 164 microseconds (millionths of a second). The half-life of ^{222}Rn is just about the right length to cause a problem in homes. Radon is the only member of the chain that is a gas, and therefore the only one apt to make its way from rocks and soil up into your home. If it had a much shorter half-life most of it would change into another solid (polonium-218) before escaping from the soil. If it had a much longer half-life, most of the radon would escape from the house before it underwent its next disintegration to form polonium-218. This is important to note because it is the polonium-218 (with a half-life of 3 minutes) and some of the other decay products that present the greatest risk. They emit relatively high-energy alpha particles that can be especially damaging when the disintegration occurs inside a person's lungs.

2. Radon Characteristics and Occurrences

Radon is a naturally-occurring radioactive gas. You cannot see, smell, or taste it. It is produced from the radioactive breakdown of radium, is found in soils just about everywhere, and continually escapes from soils into the atmosphere. Although some radon can be found in virtually every home, under certain situations it builds up to high concentrations in indoor air, thereby constituting an important health hazard. In order to understand why radon makes its way into homes, how it can build up to dangerous concentrations, and how it can damage your health, we must first introduce some basic information about radon behavior, radioactivity in general, and the radioactive decay series that leads to radon formation.

There are several different kinds or isotopes of radon, but the one that is of greatest interest and concern regarding possible health effects is called radon-222. Radon-222 is produced during a chain of radioactive disintegration reactions that begins when uranium-238 starts to break down. The uranium-238 is widely distributed in rocks and soils throughout the earth's crust. Most kinds of rocks and soils have some uranium, but usually only a small amount. At each stage in the radioactive decay series, one or more types of radiation is given off, and one radioactive element changes into another. There are eight different elements involved in the series, beginning with uranium-238. Eventually, a stable (non-radioactive) isotope of lead is formed, and the sequence of reactions comes to an end. All of the elements in the chain except radon are solids and tend to stay in place within the rocks and soils where they are produced. Radon, a gas, is the exception. There are five major reasons why radon can be a problem in your home:

1. It is a gas and can therefore move through, and out of, rocks and soils underneath your home.

2. It lasts for several days (that is, has a half-life of 3.8 days) before it breaks down into the next element in the series.

3. It is nonreactive chemically, and therefore does not get tied up in chemical compounds. This allows it to escape from soils into the atmosphere.

4. Radon itself is not the major hazard to biological tissues, but polonium and other radon decay products that are formed when the radon decays can be very damaging inside the lungs.

5. Human senses cannot detect the presence of radon, regardless of how high the concentration, because it is odorless, tasteless, and invisible.

3. Entry into Homes

Most of the radon found in indoor air comes from the rocks and soils around the home. Some building materials and well water can also be important sources in certain cases, but by far the most important contributor is the ground under the home. Some kinds of rocks, and the soils formed from their breakdown, are more prone to giving off radon than others. These are rocks that have high concentrations of uranium, especially some granites and gneisses, marine shales, and some limestones.

Radon moves through cracks and fissures in rock and through the air spaces in soil to make its way into the home. The type and depth of soil present (especially pore size, density, etc.) and locations of cracks in the underlying rock materials are important factors influencing radon movement upward to the base of a house. It enters via numerous small cracks and openings found in the foundation, concrete slab, and walls. Indoor air concentrations are influenced by the number and size of such openings from the soil and the amount of household ventilation. Concentrations tend to be highest in cold climates during the winter because ventilation is usually reduced during cold seasons (i.e., windows are kept closed), and hot air rising to escape at the top of the house causes a slight vacuum in the lower parts of the house. Radon-contaminated air is pulled into the house from the bottom to fill the vacuum. Because the radon enters at ground level and is removed by ventilation, concentrations tend to be highest on the lower floors of the house, especially the basement. In apartment buildings, radon concentrations are seldom high enough to cause concern above the second floor.

4. Health Effects

Radon causes human health effects primarily via alpha particle emissions of the radon decay products, especially polonium-218 and polonium-214. These radioactive disintegrations in the air inside the home are of little concern because the emitted alpha particles are easily stopped by a couple of centimeters of air, and they are unable to penetrate your skin. Unfortunately, protection provided by skin is not available inside the lungs, and the alpha particles emitted inside the air passages in the lungs by some of the disintegrating decay products are sufficiently powerful to penetrate the lung lining (epithelium) and damage a layer of sensitive cells called basal epithelial cells. This damage can sometimes lead to lung cancer.

The main air passages leading from the trachea (windpipe) to the lungs are called bronchi. At the ends closest to the mouth, bronchi are lined with tiny hairs, called cilia, that help to trap particles present in the air, including the inhaled radon decay products. The outer layer of the epithelium is comprised of mucus-secreting cells. The mucus also helps to clear away foreign substances. Some of the alpha particles emitted by the radon decay products have sufficient energy to penetrate through the outer layer of epithelium and reach the sensitive basal epithelium. Cell division occurs rapidly here, and this layer is therefore prone to development of cancer. Cancer is uncontrolled cell division. Damage is a function of the thickness of the layer of outer epithelial cells and the energy level of the alpha particles that are emitted during radioactive disintegration inside the bronchi.

Scientists and medical professionals don't have a complete understanding of how radiation damages biological tissues. A current theory is that radiation destroys important chemical bonds in molecules by a process called ionization, which is essentially knocking electrons off neutral atoms to form ions (positively or negatively charged atoms or molecules). This damage appears to be a particular problem in DNA, resulting in the death of individual cells or development of abnormal cellular growth patterns. DNA is a long, thread-like molecule made up of chains of nucleotides that contain encoded genetic information. When the DNA molecule is broken, it can repair itself. If DNA is repeatedly damaged, there is an increased possibility that repairs will be incorrect. Faulty repair can result in an error in the sequence of nucleotides that provide the correct genetic information for cell division. Such coding errors are believed to lead to gene mutation, and sometimes to cancer. Although there are thousands of different substances that are suspected of causing cancer, there are only about two dozen known human carcinogens. Radon is one.

It is difficult to give precise information on the cancer risks from radon contamination in indoor air. We know from studies of underground miners that high concentrations of radon in the air increase the chances of developing lung cancer. Exposure to large amounts of radon appears to increase the cancer risk. Quantification of the risk associated with indoor exposure to concentrations that are lower than those found in the mine studies depends on what assumptions are made about the relationship between the dose of radiation received and the incidence rate of cancer in those who receive the dose. Age and sex differences and other factors, especially smoking, also influence the actual risk. Recent epidemiological studies of household radon exposure suggest, however, that a linear extrapolation from the miner studies to household exposure risks appears reasonable. Although we don't know how many people die each year from lung cancer caused by radon, estimates for the United States range between about 5,000 and 20,000 deaths per year. This is about 10% of the lung cancer deaths attributed to smoking.

5. Measurement

a) *Units of Measure*

There are a number of systems in use for measuring radioactivity. Some are based on the number of radioactive disintegrations that are given off by the radioactive material during a given period of time, and some are based on the amount of radiation that is actually absorbed by a person, or a rat, or whatever. The basic unit of measurement most commonly used in the United States for radioactivity is the curie, expressed as the symbol "Ci". One curie is equal to 37 billion radioactive disintegrations per second; that is a lot of radioactivity! The radioactivity given off by radon and its decay products is usually measured in picocuries (pCi), or trillionths of a curie.

Because the number of pCi tells only how many disintegrations are occurring per unit of time, it is also important to give some information on the space in which those disintegrations are occurring. For example, there are large differences in the amount of radioactivity in the following:

- 1000 disintegrations per second per house
- 1000 disintegrations per second per 10 x 12 x 8 ft living room
- 1000 disintegrations per second per cubic centimeter of household air.

For convenience, household radon levels are expressed as the number of radioactive disintegrations that occur within a liter of air, in picocuries of radioactivity per liter of air (pCi/L).

As discussed above, radon decay products, not the radon itself, are the major culprits in causing lung damage. The decay products of radon are much more difficult to measure because they are solids, whereas radon is a gas. The solids become attached to particles in the air, to furniture, to your cat, and so on. A reasonable measurement of the radon gas concentration in the air will provide a pretty good indication of the concentration of radon decay products. Measurements need not, and cannot, be highly precise. Every time you open the door, build a fire in the fireplace, turn on the kitchen or bathroom fan, or do scores of other routine things, the radon concentration in the air you breathe changes. There is quite a bit of variability in the levels found from room to room in the house, throughout the day, and from season to season.

b) *Levels of Safety and Concern*

Regardless of the variability in measured concentrations, we still need to know what constitutes a "high" concentration. At what level should I become concerned? Should I panic, leave the house, and move to an island in the South Pacific? What is a "safe" level? There is no totally safe level of radon in your household air, any more than it is ever totally safe to hop in your car and drive to the grocery store. You might develop lung cancer from exposure to "low" levels of radon over many decades, or you might get creamed by a Mac truck on your way to the store. The EPA recommends 4 pCi/L as an "action level" for radon in homes. In other words, if the average levels in your home are above 4 pCi/L, EPA scientists think it would be prudent for you to do something about it. This action level is based partially on the study of cancer incidence in underground miners, partially on laboratory animal experiments, and partially on practicality. It is generally possible to reduce indoor concentrations to 4 pCi/L or below. Thus, the 4 pCi/L level is an "achievable" goal for homeowners in trying to minimize their health risk. It is important to realize that standards are subjective. A person with lungs that are highly susceptible to lung damage from radon decay products might be at greater risk in a home with 4 pCi/L of radon than a very healthy individual living in a home with 10 pCi/L of radon.

c) *Methods of Measuring Radon*

Because radon is undetectable by human senses, no matter how high the levels might be, it can only be detected by a test. There are several ways to measure the radon concentrations in your home. Each method has its advantages and disadvantages. The three most common types of radon detectors used for home testing are the charcoal canister, alpha track monitor, and electret ion chamber. Charcoal canisters are used for short term tests (2-7 days) and measure radon gas by adsorption. Alpha track monitors are for long term tests (3-12 months) and measure radon gas by recording the tracks of alpha particles emitted when the radon decays. The electret ion chamber contains a specially charged device that when exposed to the air reacts to the radiation emitted from radon and its decay products. The electret ion chamber can be used for both short and long term tests.

The recommended procedure for all homeowners is to begin with a short term test. Depending on the results of the initial test, a homeowner may need to do additional confirmatory testing. For specific information about testing procedures, interpretation of test results, and mitigation or remediation actions, individuals should contact their state radon programs. See Resources, State Radon Programs.

6. Mitigation

Mitigation is a term that is used to mean "fixing the problem." If your tests suggest that the radon levels are too high, and you want to do something about it, then the next step is to implement one or more mitigation strategies to decrease the radon concentration and thereby decrease your health risk. There are many different radon mitigation techniques, but they all involve one of two things: 1) keeping radon from leaking into the house, and 2) once radon gets into the house, ventilating it out. The best approach or combination of approaches to use will depend on such things as:

- how high the test results are
- the design and air flow patterns of the house
- the cost of different strategies
- appearance (i.e., exposed ventilation pipes in the basement).

Specific strategies might include sealing the cracks and openings in and around the concrete slab under the house and the foundation, increasing ventilation with fans or heat-exchangers, or drawing soil gas away from the house before it enters. Some corrective measures can be implemented by the homeowners; some require the skills of a professional radon contractor. The cost of effective mitigation may vary from $100 to a few thousand dollars. The work itself can be done by a homeowner or a professional radon contractor. Regardless of who does the work and how much it costs, confirmatory testing should *always* be done to see how successful the mitigation has been.

IV. LESSON PLANS

This section contains ten individual lesson plans and the accompanying teacher's notes. They are structured to be stand-alone units, which can be used in the classroom either individually or as a group. However, lesson plans #2 (What is Radioactivity?) and #3 (What is Radon?) should be considered as necessary prerequisites to those that follow (#4 - #10).

The radon topic is, by its very nature, multidisciplinary. This is a major factor that makes radon both interesting and challenging to students. It allows exploration of a multifaceted and relevant topic, while building process learning skills and higher order thinking skills in the students. Few individuals, however, possess sufficient background in all of the relevant disciplines to fully understand the major factors that can come into play in an integrated discussion of radon. We therefore recommend that you, the teacher, carefully review the background information provided in Section III prior to proceeding with the individual lesson plans.

In completing many of these lesson plans, students will analyze, graph, and interpret different kinds of data. Students are encouraged to manipulate the data in such a way as to draw meaningful conclusions. All of the exercises can be completed without using a calculator or computer. However, the activities have been carefully selected to allow students to enter their data into a computer spreadsheet format using the software program LabQuest. The LabQuest Graphing option will then allow students to display their data in one or more graphic outputs. LabQuest is available to all high schools in New Jersey and provides a user-friendly computing tool specially designed for the classroom environment. See Appendix C, Resources, for more information on LabQuest teacher training workshops in your area.

TEACHER'S NOTES I

WHAT DO YOU THINK ABOUT RADON?

BACKGROUND

Students and their parents are going to complete a survey about radon to discover what their knowledge is about the subject. Once they have completed the surveys, have them compute the mean scores for each question on the tally sheet using a calculator. The mean scores can then be entered into the LabQuest Spreadsheet for graphing. Instructions for using LabQuest can be found in Appendix A. Alternatively, the data can be graphed by hand if the LabQuest software is not available.

MINIMUM RECOMMENDED TIME ALLOCATION

Allow part of one class period to complete the student survey and have the parent survey completed that evening. Allocate one additional class period for data analysis and discussion.

STUDENT RESPONSES

Provided below is a summary of student responses to the survey questions. The primary purpose of the survey is not to evaluate the correctness of the responses, but rather to introduce some of the key concepts that are presented in the lesson plans that follow. Use these data for comparison.

Question Number	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Student Response	1	4	1	4	5	2	5	2	5	1

EXTENDED ACTIVITIES

1. Have students recalculate means and differences for males vs. females, rather than parents vs. students. Graph and compare these data to determine if a significant difference exists.
2. Have students create their own survey to determine the perceptions of students and parents about other contemporary environmental issues.

INVESTIGATION I

WHAT DO YOU THINK ABOUT RADON?

INTRODUCTION

Surveys are increasingly becoming an important fixture in American life. Politics, public policy, marketing, and planning are driven largely by surveys of one kind or another. Commercial agencies make a business of conducting sample surveys for clients. Market research keeps manufacturers and retailers continuously informed regarding people's reactions to new products, packaging, and preferences. Surveys can also provide useful and current information regarding people's perceptions about, or knowledge of, relevant social issues. **In this exercise you will conduct two surveys concerning opinions and/or knowledge about radon. The first will be a survey of students and the second a survey of parents/guardians.**

OBJECTIVES

To determine perceptions about radon, including its physical properties and its economic, social, and personal consequences.

MATERIALS

- LabQuest Level 2 software (helpful, but not required)
- Radon Survey

PROCEDURE

1. Complete the student survey (Radon Survey).
2. Take home one or two copies of the survey for your parent(s)/guardian(s) to complete and return to class.
3. Use the tally sheet format illustrated below to determine the mean values for each question from students and parents.

Question	Response					Total	Mean
	1	2	3	4	5		
1 Total People	//	////	//	//	/	//	
Point Value	1x2=2	2x4=8	3x2=6	4x2=8	5x1=5	29	2.64
2 Total People	~~////~~ //	/	//		/	//	
Point Value	1x7=7	2x1=2	3x2=6	4x0=0	5x1=5	20	1.82
Continue for all questions in the survey.							

Figure 1. Example showing tally sheet computations.

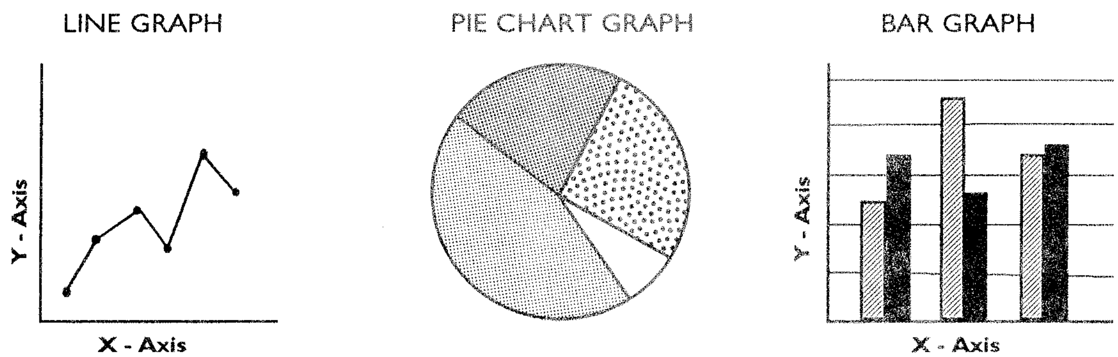
DATA COLLECTION

4. Use the LabQuest Spreadsheet to enter the class' and parents' mean score and difference for each question or tabulate the differences as shown below. See Appendix A for instructions on how to use LabQuest.

Question	Student Mean	Parent Mean	Difference
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

5. Plot a graph of your data either by hand or by using the Graph option from the LabQuest Spreadsheet. See Appendix A for instructions on how to use LabQuest.

EXAMPLE GRAPHS



In a line graph, data points are plotted on the graph and then connected by a line. The line can either connect each point to the next or approximate the pattern displayed by the data points, as shown above. In a bar graph, the height of each bar corresponds to the values on the y-axis. Bar graphs and pie charts are good when you want to combine a lot of data points into different categories. Each category will then be displayed as one bar or one slice of the pie.

The following guidelines will help you to draw clear, easily-interpreted graphs:

1. Determine which set of numbers will be shown on which axis. If you think that one variable (set of numbers) might be causing the other variable to be affected, then it is best to put the variable suspected of causing the effect on the x-axis (horizontal) and the affected variable on the y-axis (vertical).

2. Choose scales for each axis. They don't have to be the same. They don't have to start at zero, and sometimes can include negative numbers. Choose scales that allow you to clearly show all of your data points without having a lot of empty space.

3. Number the major divisions along each axis, label each axis, and when possible show the units used.

ANALYSIS (Your responses should be complete sentences.)

6. Which question(s) had the least amount of difference in responses between students and parents? To what do you attribute this result?

7. Which question(s) had the greatest amount of difference in responses between students and parents? To what do you attribute this result?

CONCLUSIONS

8. Looking at the data from students and parents, what is your impression of opinions that people have about radon?

9. What questions would you like to know more about as a result of taking this survey?

RADON SURVEY

Name: ______________________________ Date: ____________

Sex (circle one): Male Female

Age status (circle one): Student Parent/Guardian

PROCEDURE: Complete the survey below by circling the response that most closely represents your feeling or perception about the question (1-Strongly Agree, 2-Agree, 3-Neutral, 4-Disagree, and 5-Strongly Disagree).

		Strongly Agree	Agree	Don't know or Neutral	Disagree	Strongly Disagree
1.	Radon is a health hazard.	1	2	3	4	5
2.	Radon causes bone cancer.	1	2	3	4	5
3.	Radon is a naturally occurring radioactive gas.	1	2	3	4	5
4.	Radon enters homes mostly through windows, and cracks in ceilings and roofing.	1	2	3	4	5
5.	At high concentrations, radon can be detected by its smell.	1	2	3	4	5
6.	Radon levels in a home are related to the air flows within the home.	1	2	3	4	5
7.	Significant amounts of radon come from natural gas and home furnishings.	1	2	3	4	5
8.	Tests to screen for radon are simple to perform and inexpensive.	1	2	3	4	5
9.	All traces of radon can easily and inexpensively be eliminated from a home.	1	2	3	4	5
10.	There is natural radiation around us all the time.	1	2	3	4	5

TEACHER'S NOTES 2

WHAT IS RADIOACTIVITY?

BACKGROUND

Most people, including most students, need to have more knowledge about the phenomenon of radioactivity because radioactivity and radioactive substances are natural and important parts of our daily lives. Please be sure that you review the material presented in Section III-Background Information on Radon before beginning this lesson plan. It is important for students to recognize that the half-life of the radioactive element as well as the kind of radiation emitted and the energy of the radiation determine any possible biological effects from radiation.

The half-life of an isotope is important in influencing the behavior and effects of the isotope and its radiation. Half-life tells us how long the isotope will last before decaying into something else. It also provides information on the frequency of radioactive disintegrations. An extremely long-lived radioisotope (radioactive isotope) will only infrequently emit its radiation. A radioisotope with a short half-life will repeatedly emit its radiation during a short period of time. The concept of probability will help students understand radioactive half-life. The procedures outlined in this lesson plan should help communicate this concept to the students.

Note: If you write a letter on school stationery to the M&M/Mars Candy Company, you can get a coupon for a free bag of m&m's to use in this exercise. Have the students compose the letter, and also compose a "thank you" letter afterwards. See Resources, Equipment/Materials.

MINIMUM RECOMMENDED TIME ALLOCATION

One class period.

WARM UP

This lesson plan should be preceded by a hands-on geiger counter activity, which will help tremendously to get the students excited about the content material. Have students record changes in the amount of radioactivity detected by the geiger counter in response to 1) changing the distance from the radioactivity source, and 2) shielding the source with different kinds of materials (e.g., paper, thin plastic, aluminum foil, wood, etc.). See Resources, Equipment/Materials.

STUDENT RESPONSES

Question 7: The appropriate response is one roll.
Question 8: The appropriate response is two rolls (one-half of one-half to arrive at 1/4 remaining).
Question 9: The appropriate response is one roll.
Question 11: The appropriate responses are as follows:

- 4.5 billion years
- 2.5 billion years
- about 18 billion years.

EXTENDED ACTIVITIES

1. Introduce a literature connection to radon by having students interpret a political cartoon relating to radiation exposure, radon, etc.
2. Have students research current articles in periodicals relating to radiation in general, including both beneficial uses and harmful effects. See Resources, Information Resources.

INVESTIGATION 2

WHAT IS RADIOACTIVITY?

INTRODUCTION

The study of probability allows us to make predictions about the occurrence of certain events such as birth, death, and accident rates, and in this case, the breakdown of atomic nuclei during the radioactive decay process. Radioactivity is emitted when particles or energy rays are given off by an atom's nucleus (See Figure 1). Three different kinds of radiation can be given off: alpha, beta, or gamma (Figure 2). During this "decay" process, the element spontaneously gives off particles or energy rays, known as radiation. Radon-222 is the direct product of the decay of the most common radium isotope, radium-226. Radium is a product, several steps removed, of the decay of the most abundant uranium isotope, uranium-238. Radon-222 breaks down into its decay product isotopes, polonium-218, among others. Decay product isotopes are sometimes referred to as progeny or daughters.

Each element has a characteristic average rate of decay that doesn't change. The time it takes for one-half of the atoms in a given radioactive sample to decay is called the half-life of that isotope. Each radioactive isotope has its own unique half-life, which is totally unaffected by temperature, pressure, and other factors. **In this exercise you will conduct an investigation that simulates radioactive half-life and its relationship to statistical probability.**

OBJECTIVE

To apply the process of probability to the concepts of radioactive decay and radioactive half-life.

MATERIALS

- LabQuest Level 2 software (helpful, but not required)
- One large bag of m&m's (plain)

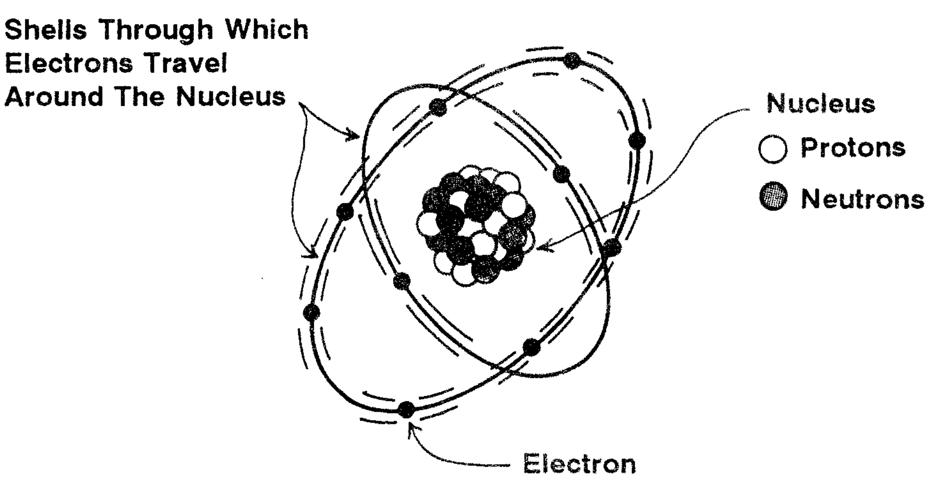


Figure 1. Anatomy of an atom.

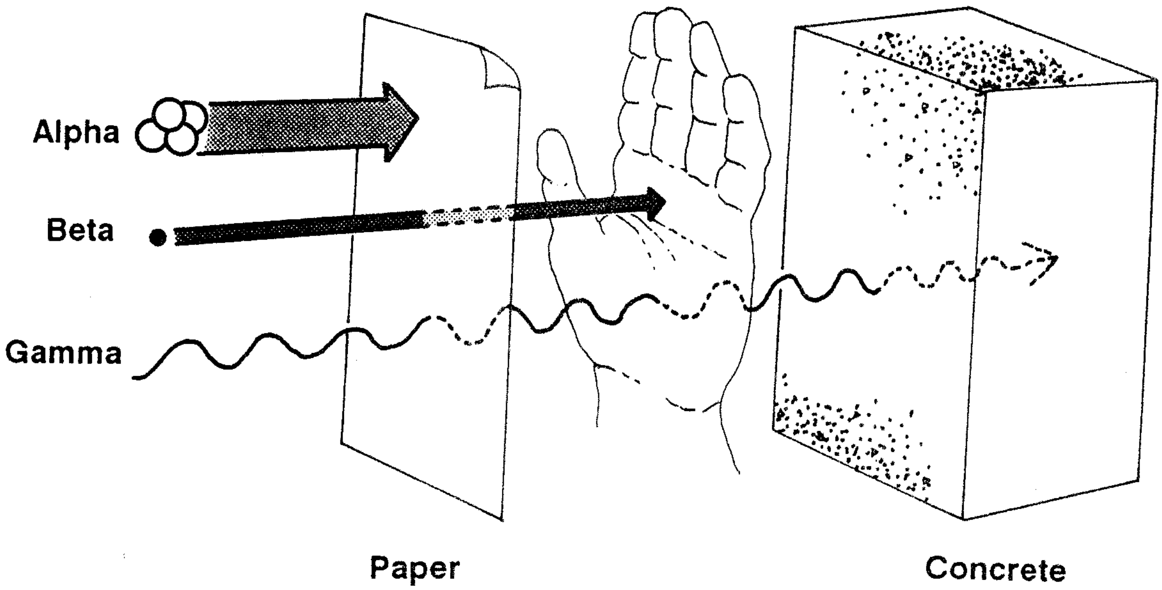


Figure 2. Penetrating power of radiation. Alpha particles are relatively large, but are easily stopped by a piece of paper or a layer of skin. Beta particles are much smaller, travel at high speed, and can penetrate the skin. Gamma radiation has no mass, travels at the speed of light, and can go right through the body.

PROCEDURE

Note: Each m&m in the bag represents a radioactive atom. An atom decays and emits its radioactivity when the side marked ''m'' turns up. It is removed from the pile before the next roll.

1. Begin by rolling all m&m's (atoms). You may eat some, but be sure to begin the procedure with at least 100 atoms. Eat the yellow ones; it is hard to see the ''m'' on them! Remove any atoms that decay (the side marked ''m'' turns up). Record your results in table format.

2. Continue rolling all active atoms until all of them have decayed.

3. Do you think the results would be exactly the same if you rolled the radioactive atoms again? Why or why not?

____

____

____

____

____

DATA COLLECTION

4. Make at least five trials, each time starting with a full bag of radioactive atoms. As in Step 1, roll the radioactive atoms repeatedly until they have all decayed into a new isotope.

5. Use the LabQuest Spreadsheet to enter the data from your experiment for each of the five trials. See LabQuest instructions in Appendix A.

6. Plot an X/Y graph of your data, using the Graph option from the LabQuest Spreadsheet. If the LabQuest software is not available, you can plot the data by hand.

Note: The half-life of a radioactive substance is the time it takes for half of the atoms to decay.

ANALYSIS

7. How many rolls were necessary (on average) before half of the atoms decayed?

Note: Each roll represents one half-life for your m&m's.

____

8. How many half-lives were necessary (on average) before 3/4 of the atoms decayed?

____

Explain why you obtained this result, in terms of the definition of half-life.

____
____
____
____
____

9. How many *additional* rolls do you think it would take to deplete the pile if your starting pile was twice as large?

____

10. Perform several trials to check your prediction.

11. You are given 10 grams of pure uranium-238 on January 1. Its half-life is 4 1/2 billion years, and it decays to form thorium-234.

a) How long would you have to wait before half of it turned into thorium-234?

____

b) How much would you have left after 9 billion years? ______________

c) How long would you have to wait before you had only 1/2 g left?
Hint: Use graphing techniques to approximate the length of time.

____

CONCLUSIONS

12. In your own words, explain the half-life of an element.

13. Why do you think half-life is an important concept in the study of radon?

TEACHER'S NOTES 3

WHAT IS RADON?

BACKGROUND

Students may have some difficulty understanding the relationship among the isotopes in the uranium-238 decay series (Figure 1). Each time an alpha particle is emitted during the series, the number of protons decreases by 2 and the number of neutrons decreases by 2. This is because an alpha particle consists of 2 protons and 2 neutrons. The atomic number is the number of protons. The mass number (i.e., the 238 in uranium-238) is the number of protons *plus* the number of neutrons.

When a beta particle is emitted, the mass number stays the same because no protons or neutrons are emitted. A beta particle is an electron, with very slight mass and a negative charge, and is formed when a neutron breaks apart into a proton and electron. The atomic number increases by one when a beta particle is emitted. This can be thought of as a conversion of one neutron into one proton to compensate for the loss of the negatively-charged beta particle. Thus, even though the atomic number changes, the mass number stays the same during beta emission.

The half-life of each isotope is given below its symbol in the figure. Half-life is an important characteristic of each isotope, and can be a difficult one for students to grasp (see Lesson Plan 2).

MINIMUM RECOMMENDED TIME ALLOCATION

One class period.

STUDENT RESPONSES

Question 3: Radon would be a *lesser* health threat if the half-life was either very short (it would not make its way out of the soil before being transformed from a gas to a solid) or very long (it would escape from the house before it decayed to polonium).

Question 4: Answers may vary.

Question 5: Use the same reasoning as in Question 3. The polonium would likely be cleared from the lungs prior to emitting its radioactivity if the half-life was as long as 20 days. Remember that it is the radioactive emission *inside the lungs* that causes the problem.

Question 6: The properties of radon that contribute to its importance as a health concern include:

- it is a gas and can escape from soil into the house
- it has a medium-length half-life relative to the movement of gas (air) into and out of the house
- it decays to form a solid that can lodge in the lungs
- its immediate decay product has a high-energy (potentially damaging) alpha emission
- its immediate decay product has a short half-life, and therefore has a high probability of decaying while inside the lungs.

Question 7: Radon is a gas and as such can move through cracks and fissures in rock materials. In order to move 100 feet within radon's half-life of 3.8 days, the rocks would have to contain major cracks or faults.

EXTENDED ACTIVITIES

1. Have students research the origin of key terms used in this lesson plan and throughout the teacher's guide (e.g., radon, radioactivity, isotope, curie, electron, etc.)

2. Have students compute an estimate of how long it would take to form lead-206, starting with a quantity of uranium-238. Have students explain what factors influence this time estimate (e.g., statistics and probability) and the limitations caused by the few very long-lived isotopes such as U-238, U-234, Th-230, and Ra-226. Students will need to use the data presented in Figure 1. to evaluate this problem.

3. Have students conduct an electronic (computer) literature search for an aspect of the radon issue, such as mitigation techniques, measurement devices, or health effects.

INVESTIGATION 3

WHAT IS RADON?

INTRODUCTION

Radon is a naturally occurring radioactive gas. It is formed by the radioactive breakdown of radium, and is found in soils just about everywhere. You cannot see it, taste it, or smell it. It is continuously formed in rocks and soils and escapes into the atmosphere. In some cases, it makes its way into homes, builds up to high concentrations in indoor air, and can become a health hazard.

Although there are several different isotopes of radon, the one that is of greatest concern as a potential human health threat is called radon-222. Radon-222 is formed naturally during a chain of radioactive disintegration reactions (decay series). The decay series begins when uranium-238 decays. Uranium is widely distributed in rocks and soils throughout the earth's crust. It has a half-life of 4.5 billion years, which means a very slow breakdown. The decay series is shown schematically in Figure 1. There are eight different elements and 15 different isotopes in the series, beginning with uranium-238 and ending with lead-206. New elements formed by radioactive disintegration reactions are called decay products. Thus, radium-226 is one of the decay products of uranium-238. Polonium-218 and lead-214 are decay products of radon-222. The final isotope, lead-206, is stable (non-radioactive) and its formation ends the series. All of the elements in this series are solids, except radon.

> **Radioactivity** - the spontaneous emission of energy by certain (radioactive) atoms, resulting in a change from one element to another or one isotope to another. The energy can be in the form of alpha or beta particles and gamma rays.

Because radon is a gas, it moves freely in air spaces between rocks and in soils. It becomes a human health concern when it leaks from the underlying soil into homes and other buildings. If it builds up to high concentrations in indoor air, radon and its decay products can be inhaled and cause lung cancer. The isotopes in the series that are most damaging to biological tissues are the polonium decay products of radon, primarily when they undergo radioactive disintegration inside the lungs. **In this exercise you will examine the characteristics of the principal uranium decay products and their relationship to the radon health issue.**

> **Isotopes** - Two or more forms of the same element which have the same number of protons, but a different number of neutrons in their nuclei.

OBJECTIVES

To identify what radon is, how it is formed, and why it is a human health concern.

PROCEDURE

1. Examine the data presented in Table 1, showing some characteristics of selected isotopes in the uranium-238 decay series, and the following text box, on page 29, showing the various kinds of radiation emitted. Evaluate the characteristics of radon and its relationship to other isotopes in the series, especially those characteristics that cause it to be a potential health concern.

2. Complete the analysis and answer the questions that follow.

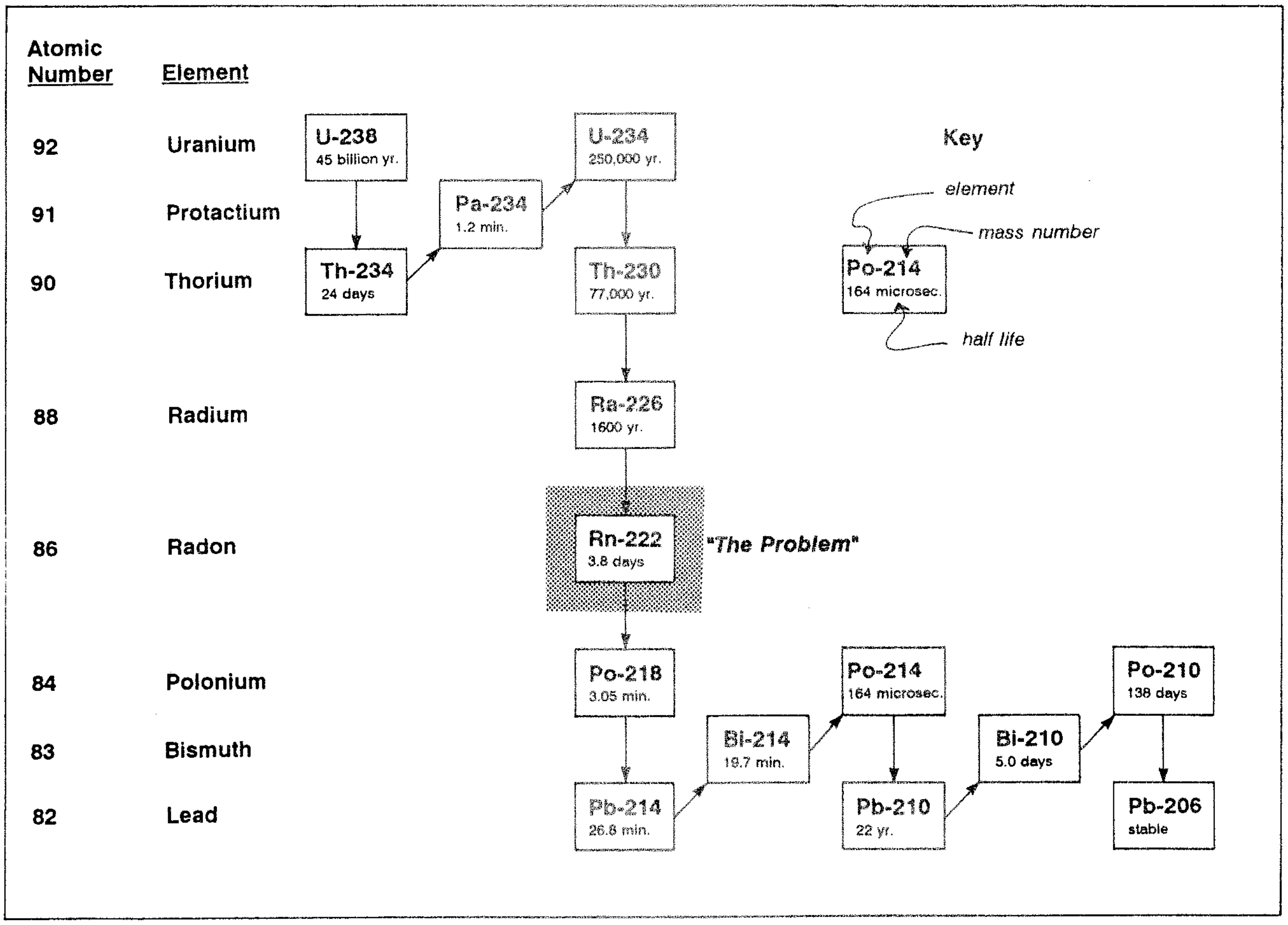


Figure 1. Radioactive decay series that proceeds from uranium-238 to lead-206. Radon-222 is the only gas formed during this series, thus allowing it to move out of the rocks and soils where uranium is found and into a home.

Table 1. The following table provides information on some of the isotopes that occur in the uranium-238 decay series.

Isotope	Physical State	Principal Radioactive Emission	Half-life	Decays to Form
uranium-238	solid	alpha	4.5 billion years	thorium-234
radium-226	solid	alpha	1600 years	radon-222
radon-222	gas	alpha	3.8 days	polonium-218
polonium-218	solid	alpha	3 minutes	lead-214
lead-214	solid	beta, gamma	27 minutes	bismuth-214
bismuth-214	solid	beta, gamma	19.7 minutes	polonium-214
polonium-214	so;id	alpha	164 microseconds	lead-210

Kinds of Radiation

Radioactive isotopes can give off three kinds of radiation: alpha, beta, and gamma. Each kind of radiation *can* damage your health under certain conditions. But the kinds of radiation are very different; they differ in how far they travel, how much energy they possess, and how much damage they are likely to do.

Type of Radiation	Relative Size	Relative Amount of Energy	Penetrating Ability
Alpha particle	large particle	great	poor - will not penetrate human skin
Beta particle	small particle	small	moderate - can penetrate human skin
Gamma ray	very small energy ray	small	good - can pass right through your body

ANALYSIS

3. Would radon be a greater, or lesser, health threat if its half-life was 1 second instead of 3.8 days? Why? What if its half-life was 50 years?
Hint: Half-life tells us how long the isotope will last before it decays into something else.

4. Does the fact that radon is the only gas in the uranium-238 decay series increase or decrease its importance as a potential health threat? Why and how?

5. The radon decay products, especially polonium-218, are more dangerous than radon itself. They emit high energy alpha particles that can damage lung tissue if they disintegrate while inside the lung. Would radon be more, or less, a health threat if polonium-218 had a half-life of 20 days, instead of 3 minutes? Why?

CONCLUSIONS

6. List 4 properties, or characteristics, of radon that cause it to be an important health concern. Explain why each property is important in influencing radon human health effects.

7. Radon has been known to reach the ground surface from one hundred feet or more below the ground. How might this occur, given the physical state and half-life of radon?

TEACHER'S NOTES 4

HOW DO YOU MEASURE RADON?

BACKGROUND

The students are given an opportunity to design initial and confirmatory radon tests for their homes. This exercise is open-ended. It should include, at a minimum, consideration of the types of detectors available (charcoal canister, alpha track, and electret ion chamber), number of detectors used, duration of measurements, placement (including consideration of how many levels are involved and whether or not the house has a basement), and appropriate placement of test devices, considering factors like moisture and ventilation rates. Closed-house conditions are important for a short term test because the objective is to obtain a "worst case" estimate. Closed-house conditions are not necessary when measuring "average" concentrations over a longer period, such as 3 months to a year.

The basic unit that is used in the United States to measure radioactivity is the curie (named for Marie Curie, the physicist and chemist who discovered radium), which is abbreviated by the symbol Ci. Its original definition was the number of radioactive disintegrations occurring per second in one gram of radium-226. However, that is a subjective definition because it is difficult to measure exactly how many disintegrations are occurring! In 1950 the curie was redefined as 3.7×10^{10} disintegrations per second; that is a *lot* of radioactivity. For most measurement purposes, radiation scientists use smaller units of a curie, such as the microcurie (μCi, one millionth of a curie) or picocurie (pCi, one trillionth of a curie) (see Table 1). Radon is often recorded in picocuries.

There are a variety of ways of measuring radiation, depending upon the type of radiation under consideration (alpha, beta, gamma), the energy of the emitted radiation, and the purpose of the measurement (See Figure 1). For specific information about radon testing, contact your state radon program. See Resources, State Programs.

MINIMUM RECOMMENDED TIME ALLOCATION

One class period.

Table 1. Some common factors used in units of measure.

Factor	Prefix	Symbol	Explanation of Factor
10^{-1}	deci	d	one-tenth
10^{-2}	centi	c	one-hundredth
10^{-3}	milli	m	one-thousandth
10^{-6}	micro	μ	one-millionth
10^{-9}	nano	n	one-billionth
10^{-12}	pico	p	one-trillionth

STUDENT RESPONSES

Question 3: The February data presented in the exercise show a pattern of highest concentrations in the mornings and lowest concentrations in the afternoons. Such diurnal variability is common, and can be attributable to radon build-up during the night in response to closed-house conditions, and more frequent ventilation during the day (opening doors, using fans, etc.).

Question 4: The March data show increased concentrations during the period of March 8 to March 12. A cold-spell *could* cause such a pattern by increasing the flow of heated air up through the house to escape at the top. This increased heat flow would likely increase the pressure differential (vacuum) that draws radon into the house at the bottom.

Question 5: The largest sudden *decrease* in radon concentration occurred on March 17. This was probably the day that Dad painted the kitchen and aired out the house. If March 17 was a Saturday, then March 1 was a Thursday.

Question 6: Answers will vary.

Question 7: Answers will vary.

Question 8: In discussing the pros and cons of the various measurements, the students should consider that the radon concentration is always changing. It is a moving target. A short-term measurement may or may not provide a snap-shot of "average" concentrations.

Question 9: The annual average concentration would probably be somewhat less than during a very cold month, mainly because of the enhanced heat flows and lessened ventilation during cold weather.

EXTENDED ACTIVITIES

If funding permits, purchase 1 to 3 charcoal canisters for students to take measurements in selected student homes or at school. Have students predict differences among results. This activity will cost about $20 to $50 (See Resources, Information Resources).

INVESTIGATION 4

HOW DO YOU MEASURE RADON?

INTRODUCTION

There are several methods available for measuring radon concentrations in indoor air (Table 1). The methods differ with respect to how they measure and as a result, what information about radon they reveal. The most popular methods for performing an initial short term test employ either an activated charcoal canister or an electret detector.

Table 1. Comparison among some commonly used methods for measuring household radon concentrations.

Method	Approximate Cost per Measurement	Typical Duration of Measurement	Ease of Use
Charcoal canister	$10 to $20	3-7 days	Easy, send through mail
Alpha Track	$25 to $100	Several months to one year	Easy, send through mail
Electret	$100 to $150	Comes in both short term (several days) and long term (several months to one year) varieties	Easy, placement and pickup by measurement business
Continuous Radon	Several hundred dollars	48 hours or longer	Difficult, requires special equipment and trained operator; provides hourly readings
Grab Sample	Several hundred dollars	Usually about an hour or less	Difficult, requires special equipment and trained operator

In this exercise you will examine and interpret some hypothetical radon measurement data. Then you will design a two-step measurement strategy for your own home.

OBJECTIVES

To apply units of radiation to the radon issue, to demonstrate an understanding of the major factors that influence a radon measurement, and to describe the interrelationships between natural variability, "average" concentrations, and the length of time employed for integrated measurements.

PROCEDURE

1. Examine the hypothetical data presented below for radon measurements in a New Jersey home. Enter these data into the LabQuest Spreadsheet, if available (see instructions in Appendix A), and graph the data using LabQuest or by hand. Answer questions 3-5 in the Analysis section.

2. Map out a strategy to perform an initial test for radon in your home, describing how many and what kind of detectors you will use, where they will be placed, and for what length of time. Assuming that the initial test gives you results around 10 pCi/L, map out a strategy for the confirmatory testing. Complete questions 6 and 7 and describe your conclusions.

DATA

The results of continuous radon measurements for the last week in February and the entire month of March in the first floor living room of a home were as follows:

Radioactivity Measurement for February

	Radon Concentration (pCi/L)				
Date	4 AM	8 AM	12 Noon	4 PM	8 PM
22	4	4	2	2	3
23	3	3	2	1	1
24	5	4	3	2	4
25	7	6	4	4	6
26	6	5	5	3	4
27	5	5	4	3	4
28	5	4	3	3	4

Note: One pCi/L (picocurie per liter) is about two radioactive alpha decay counts per liter of air per minute.

Radioactivity Measurement for March[1]

Day	Radon (pCi/L)	Day	Radon (pCi/L)	Day	Radon (pCi/L)
1	4	11	10	21	2
2	3	12	7	22	3
3	5	13	4	23	2
4	2	14	3	24	4
5	3	15	4	25	6
6	3	16	5	26	7
7	5	17	1	27	5
8	8	18	2	28	3
9	10	19	3	29	4
10	9	20	5	30	5
				31	5

[1] All data for March are reported as average concentrations during the time period 1-3 p.m.

ANALYSIS

3. Do you notice any regular pattern to the February data? Explain the reason(s) for the observed pattern.

   Note: You can use the LabQuest Spreadsheet to perform the graphing, as described in Appendix A.

4. There was a severe four-day cold spell in March. When did it occur? What evidence is provided by the radon data for March that would indicate a cold spell?

5. On a Saturday in March, the homeowner (Dad) painted the kitchen and thoroughly aired out the house for about two days. On what day of the week was March 1?

6. Describe your procedures for initial and confirmatory radon measurements in your home. Justify your choices.

7. Radon measurements are often taken under "closed house" conditions. This means that windows are kept closed for at least 12 hours prior to and during the test, fans are left off, and doors are only opened for routine entries and departures. Would you employ "closed house" conditions during an initial test, a long-term confirmatory test, or both? Why?

CONCLUSIONS

8. Given the data obtained for February and March in this exercise, discuss the pros and cons of:
   a) a single grab sample for measuring radon
   b) a 5-day screening test
   c) a one-month long integrated test

9. How might the annual average radon concentration compare with the March data presented in this exercise? Would the annual average be higher or lower than the March average? Why?

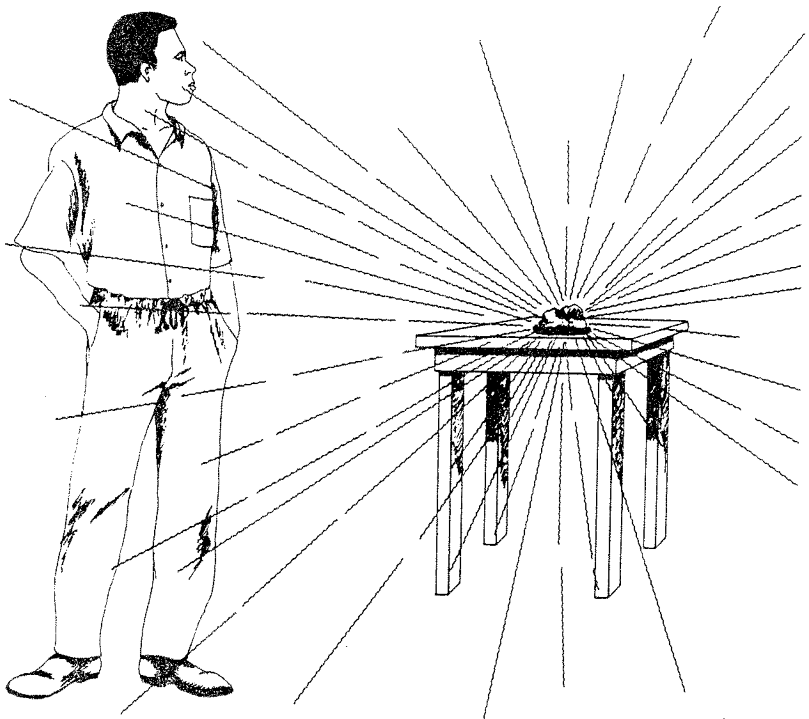


Figure 1. There are three basic ways of measuring the radiation in this scenario. The first is to measure the number of radioactive disintegrations occurring in the radioactive isotope, using a unit such as a *curie*. The second is to measure the amount of energy absorbed by the man from the radiation source, or the man's dose, using a unit called a *rad*. Note that only some of the radioactive disintegrations actually result in any dose to the man. The third way to express the radiation in this scenario is to use a unit that reflects not only the absorbed radiation, but also the amount of biological damage done by the radiation, using a unit called a *rem*. Thus, there are several different ways of looking at, and expressing, measurement of radiation.

TEACHER'S NOTES 5

WHAT ARE OUR RISKS FROM RADON?

BACKGROUND

There may be millions of homes in the United States that have elevated radon concentrations that produce lung cancer risks much higher than other environmental hazards. Despite the magnitude and widespread distribution of the radon problem, however, it has been estimated that fewer than 10% of the homes in this country have been tested. Our communication of the potential risks of radon in indoor air has been insufficient to initiate an active response on the part of the American public. This lesson plan, and others in this series, may help to fill this communication void.

People are often indifferent to the radon issue and exhibit a tendency to ignore or deny health risks. Some people are negative about radon testing, perhaps because of concerns that property values might be affected or because associated health risks are far off in time. There is also evidence suggesting that people are more apt to accept that other people's risk may be real, rather than their own. This may be from a need or desire to feel that one's home is "safe".

How do you, as a teacher, communicate risk to your students? There is no easy answer to this question. It is important for you to realize, however, that you must walk a fine line between inciting panic in some students versus combating indifference in others. This is a difficult task, and one that requires a great deal of sensitivity on your part. It is a task that calls for open discussions about risks and perceptions of risk with, and among, your students. Good luck!

MINIMUM RECOMMENDED TIME ALLOCATION

One class period.

STUDENT RESPONSES

Question 3: The graph tells you nothing about the effects of low dose. It only provides information on the effects of high dose. A model must be used to estimate the effects of low dose, based on what is *known* about the effects of high dose.

Question 6: Low dose.

Question 7: Quadratic - this model suggests the lowest effects.

EXTENDED ACTIVITIES

1. Devise a model that has a threshold and that incorporates a quadratic effect with concentrations higher than the threshold. Show a graph of the model using LabQuest.

2. Introduce the concept of risk related to environmental factors by displaying the EPA radon risk tables and graph (See Resources, Illustrations/Maps) on an overhead projector. Have students conduct a survey about risk perception using the Vermont study as an example (See Resources, Illustrations/Maps). Develop a list of environmental problems and have two groups (students and parents) rank them in order of perceived hazard.

INVESTIGATION 5

WHAT ARE OUR RISKS FROM RADON?

INTRODUCTION

It has been estimated by the U.S. Environmental Protection Agency (EPA) that between 5,000 and 20,000 Americans die each year from lung cancer caused by exposure to radon in indoor air. In New Jersey, the State Department of Environmental Protection and Energy estimates about 500 cancer deaths annually because of exposure to radon. What do these numbers mean? How do the health risks from radon compare to other environmental and safety risks? How do you make sense of perceived risks, statistical probabilities, and the combined threat of lung cancer from smoking and exposure to radon? What are the trade-offs between the economic costs of reducing your radon risk versus the benefits of a lowered probability of developing lung cancer?

There are about 200,000 deaths each year in the United States from lung cancer. It is believed that about 150,000 of those deaths are attributable to smoking. There is also strong evidence linking lung cancer to radon inhalation. This evidence comes mainly from studies of underground miners who have been exposed to *very high* radon levels and from laboratory animal experiments and some studies of radon concentrations in homes. Lung cancer deaths among miners have been studied since the 1950's, and clearly show increased incidence of lung cancer among groups of miners exposed to the highest radon concentrations (Figure 1).

Cancer mortality rates for males are about three times higher than for females, probably because men have historically smoked much more than women. The number of lung cancer deaths attributable to radon are somewhere around one tenth of the lung cancers attributable to smoking, making radon the second leading cause of lung cancer in this country. You can choose to smoke or not to smoke. You may or may not be able to choose where you live. But even if you live in a home with very high concentrations of radon, there are many ways to reduce those concentrations and thereby reduce your health risk. You don't have to live in a highly radioactive household! The first step is to learn what your risks are. Only then can you make an informed decision regarding whether or not you choose to reduce those risks.

There are four basic problems in attempting to quantify the cancer risks associated with exposure to radon in homes:

a) The underground miners who have been studied were exposed to *a lot* of radon and radon decay products in the mines. We don't know exactly how the cancer rates among those individuals compare with the risks associated with exposure to much lower levels in the home.
b) Animal studies provide useful information, but applying that data to the human population and human health risks is difficult.
c) There is generally a latency period (delay) between exposure to a cancer-causing agent and development of the cancer. This latency period may vary from 5 to 50 years and seems to be related to the age of the individual.
d) Carefully controlled studies of groups of people are difficult to obtain. People move; spend only part of their time at home; choose to smoke or not smoke; and have genetically determined predispositions to a variety of ailments.

Uncertainties resulting from these problems, among others, cause the disparity we see in different estimates of health risk. For example, typical estimates of lung cancer incidence attributable to radon exposure vary by about a factor of four-fold or more. Basically, however, all methods of estimating the risks from long-term exposure to household radon involve calculating a risk factor based on data from a small group of people (for example, miners) and then projecting this risk factor to a larger population that receives a lower dosage. **In this exercise you will examine different mathematical models to predict or describe health effects from radiation exposure.**

OBJECTIVES

To apply statistics and probability to the problem of exposure to radon in indoor air, to develop a working knowledge of human health risks and risk assessment, and to develop the skills needed to make informed decisions regarding the acceptance of health risks and appropriate needs for risk reduction.

PROCEDURE

1. Review the graph in Figure 1.

2. Interpret what the graph in Figure 1 means.

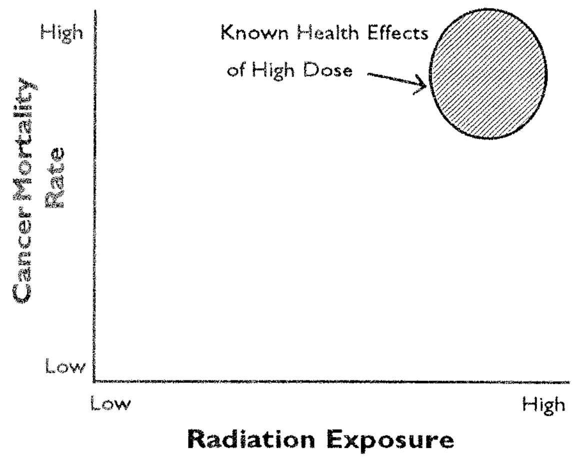


Figure 1. Relationship between radon dose and effect (lung cancer) based on studies of underground miners.

3. What does the graph in Figure 1 tell you about the relationship between dose (radiation exposure) and health effect (lung cancer) at the lower levels of radon exposure?

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4. Scientists often use mathematical models to describe or predict effects at doses that have not been well studied. Review the three mathematical models illustrated in Figures 2, 3, and 4.

DATA

Three common methods (models) used for projecting the relationship between the dose of a cancer-causing substance and the effect (development of cancer) are shown in Figures 2, 3, and 4. The linear model (Figure 2) assumes that as you increase the dose, you will see a linear increase in the effect. The threshold model (Figure 3) assumes that there is no effect at all with a very low dosage, but as the dosage increases you reach a certain threshold at which an effect is seen. The quadratic model (Figure 4) assumes that as you go to lower doses the risk decreases faster than the dose. In the quadratic model, the risk increases approximately as a square of the dose. All three models assume that there is no effect at a zero dose and all three show the same health risk at high doses because they are all based on the available data such as the underground miner studies.

Models

A model is a description, or representation, of how a system or process works. A model often uses mathematical equations to describe, as thoroughly as is practical, the workings of the system or process. For example, an atmospheric scientist studying the possibility of global warming might use models that attempt to describe global air flow patterns or the interactions between air temperature and ocean temperature. These models might be enormously complex and the calculations might require many hours of computing by the fastest and most powerful computers in the world.

Risk assessment is an area of study that attempts to quantify your health risk from various things like accidents, toxic materials, or radioactive substances. One might try to measure the health risk associated with smoking, eating large amounts of fatty foods, or exposure to radiation. Health scientists never *know* what the health risk is for these factors. But they can assemble all of the pertinent data available and *assess* what they think the health risk is. This assessment generally involves the use of one or more mathematical models. Such models start with what is known, or strongly suspected, and then predict the likely effects associated with different kinds or levels of exposure to the risk factor.

ANALYSIS

5. These three mathematical models[1] are used to estimate health risks from exposure to radon. All three use the same data for quantifying risk from high exposure (miner studies). The dose-effect relationships for the high doses are reasonably well established. The problem is to make a connection between these data and lower dose levels. Most people are exposed to much lower concentrations than the miners. What assumptions did the scientists make regarding the relationship between dose (radiation exposure) and effect (lung cancer) at the low levels of exposure for each of the three models?

Linear model ____________________

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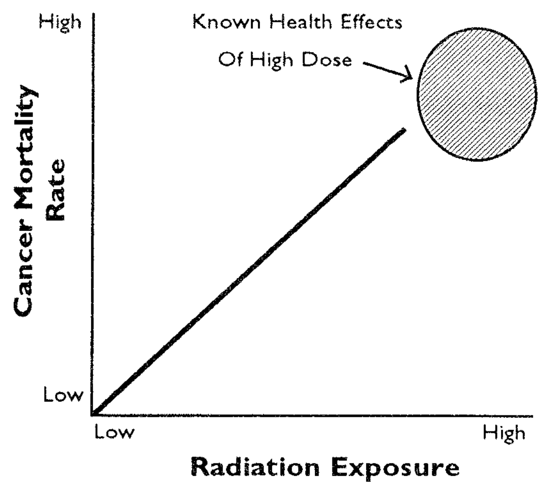

Figure 2.

[1]Modified from the National Academy of Sciences (1988).

Threshold model ______________________

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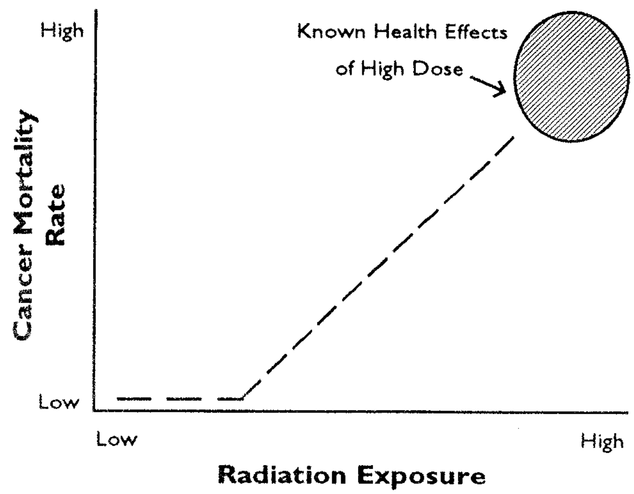

Figure 3.

Quadratic model ______________________

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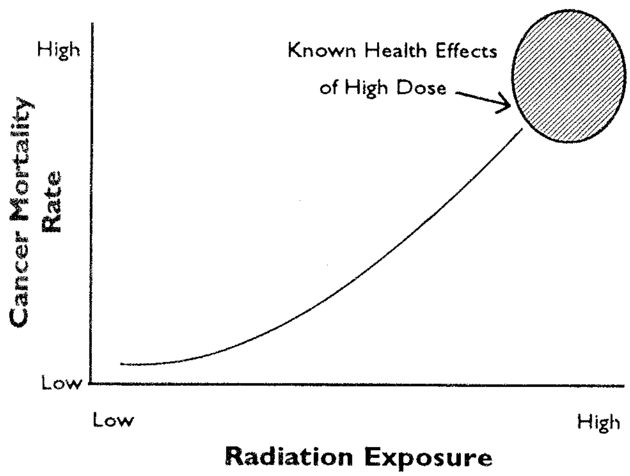

Figure 4.

6. Under what level of radiation exposure is there the greatest difference in the risk estimates for the three models?

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7. Assuming that your dose at home is equivalent to about half-way between zero dose and the dose received by the miners shown in Figures 1-4, which of the three models would you hope to be the real situation? Why?

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8. Assuming that it is your job to communicate information to the public in New Jersey regarding the public health risk of radon, which of the three models shown in Figures 2-4 will you use? Why?

CONCLUSIONS

People seem to have a *need* to be given health *standards*. They want to know what levels of a particular toxic or cancer-causing substance are "safe" and what levels will cause health problems.

9. Why is it so difficult to provide people with definite answers about health risks?

10. The U.S. Environmental Protection Agency recommends that people take action to reduce household radon levels if they are higher than 4 pCi/L on average. What would you do if your house was measured at 3.9 pCi/L?

TEACHER'S NOTES 6

HOW MUCH RADON IS AROUND YOU?

BACKGROUND

Students will conduct a radon audit of their homes in this exercise. It is intended to allow them to estimate and evaluate the major potential sources of radon entry into their homes and also to become aware of the many "unseen" routes of ventilation in the typical home. Also, it should reinforce the concept that preventing radon entry into the home and ventilating or diluting radon levels are the two processes that make effective differences in terms of reducing the inhabitants' risk from radon. The main focus of this exercise is the ventilation component, because measuring radon entry requires the purchase and processing of one or more radon detectors (*if* you have the financial resources, this would be a useful addition). Please inform the students not to take for granted that a leaky house is *necessarily* low in radon. Conducting a radon audit and drawing a schematic diagram of their homes will take a fair amount of time. These would best be done as a homework assignment. If students live in apartments above the second floor, have them work together with classmates who live on lower floors when conducting this exercise. Alternatively, they could conduct an audit of part of the school building.

Note: Remind students that when conducting a radon audit of their homes, there are places that can't be seen, and therefore will not be included when calculating total ventilation.

MINIMUM RECOMMENDED TIME ALLOCATION

Allow two days for the homework portions (home audit and schematic drawing) and one class period for analysis and discussion.

STUDENT RESPONSES

Question 3: Answers will vary.

Question 6: Answers will vary.

Question 7: Typical responses might include:

- increase air flows (ventilation) to rid the house of excess radon
- seal cracks in basement floor or foundation
- spend less time in the basement
- sleep in room with window open

Question 8: The information in this exercise provides absolutely zero information regarding the radon concentrations in any home. It merely helps the students evaluate the factors that might exacerbate or ameliorate what ever radon problem exists. They need to know *how much* radon is leaking in from underground. The only way to get an estimate of that is to take some radon measurements in the home.

EXTENDED ACTIVITIES

1. If a student in the class has had radon measurements taken at his/her home, have that student do a special assignment to report to class what was done, why, and what the results were.

2. Purchase one or two short-term radon detectors and use them to measure the radon levels in the classroom or some other portion of the school. See Resources, Information Resources.

INVESTIGATION 6

HOW MUCH RADON IS AROUND YOU?

INTRODUCTION

There are three principal sources of radon found in indoor air: 1) rocks and soils under the building, 2) building materials used in construction, and 3) radon dissolved in the water supply. Of these three, the rocks and soils under the building are by far the most important. Some kinds of rocks, and the soils that form from their breakdown, are more prone to giving off radon than others. This is because some rocks contain more uranium than others, especially some granites and gneisses, marine shales, and some limestones.

Radon is a gas which can move through cracks and fissures in rocks and through the air spaces in soil. The major factors that influence the movement of radon into a home include the uranium and radium concentrations of the rock and soil materials beneath the home, pathways through the rocks and soil to the base of the home, openings from the soil directly into the home, and the amount of suction created by air flows within the home. Once radon gets into a home, its concentration in the indoor air is influenced by the amount of household ventilation. Opening windows and doors, operating bathroom and kitchen fans, and operating clothes dryers all tend to change the radon concentrations by increasing ventilation and/or by pulling more radon in from the soil to the lower levels of the home. Because radon enters the home from the underlying soil, it seldom reaches high concentrations above the second floor of a building. If you live on a higher floor, for example in an apartment building, you should carry out this exercise with a classmate who lives closer to the ground floor. **In this exercise you will conduct a radon audit of your home.**

OBJECTIVES

To identify sources of radon entry into homes and factors that influence radon concentrations in indoor air.

PROCEDURE

Students will conduct a radon audit of their homes to determine possible areas for radon entry into the home and to estimate the extent of household ventilation. Students will discuss factors influencing radon accumulation in their homes and strategies for reducing radon levels.

DATA GENERATION

1. Draw a schematic diagram of your entire home, illustrating the major potential routes of radon entry from beneath the home.

2. Using a tape measure and calculator, estimate the total size, in square centimeters, of all visible cracks, openings, and holes in your home that increase the ventilation inside the home even when all windows and doors are kept closed. Add three square centimeters to your total for each fan that is ducted to the outside and six square centimeters for each fireplace or woodstove. Divide the total size of all openings to the outside by the total area (also in square centimeters) of the *outside* walls, floors, and ceilings in the home. Do not include the area of inside walls, floors, or ceilings between floors. This calculation will give you the estimate of the ratio of air leaks to surface area of your house.

ANALYSIS

3. List what you believe to be the three most important routes of radon entry into your home.

(1.) ______________________________

(2.) ______________________________

(3.) ______________________________

4. Use the LabQuest Spreadsheet and Graph to record the total amount of ventilation for each home in your class. If LabQuest is not available, graph the data by hand using a bar chart.

5. Assuming that the concentrations of radon in the air inside your home exhibit the following pattern, determine the person in your family who has the greatest exposure to radon at home.
   - basement (or crawl space if there is no basement) - highest concentration
   - first floor - 1/2 the concentration in the basement or crawl space
   - second floor (if present) - 1/2 the concentration on the first floor
   - all higher floors 1/10 the concentration in the basement or crawl space

Hint: You will need to estimate the average number of hours per day each family member spends on each floor of the home.

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6. How do the routes of radon entry into your home compare with the homes of your classmates? How about the total amount of ventilation under closed-door conditions?

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CONCLUSIONS

7. List three actions that you could take if you wanted to reduce the radon concentrations that *you* are exposed to inside your house?

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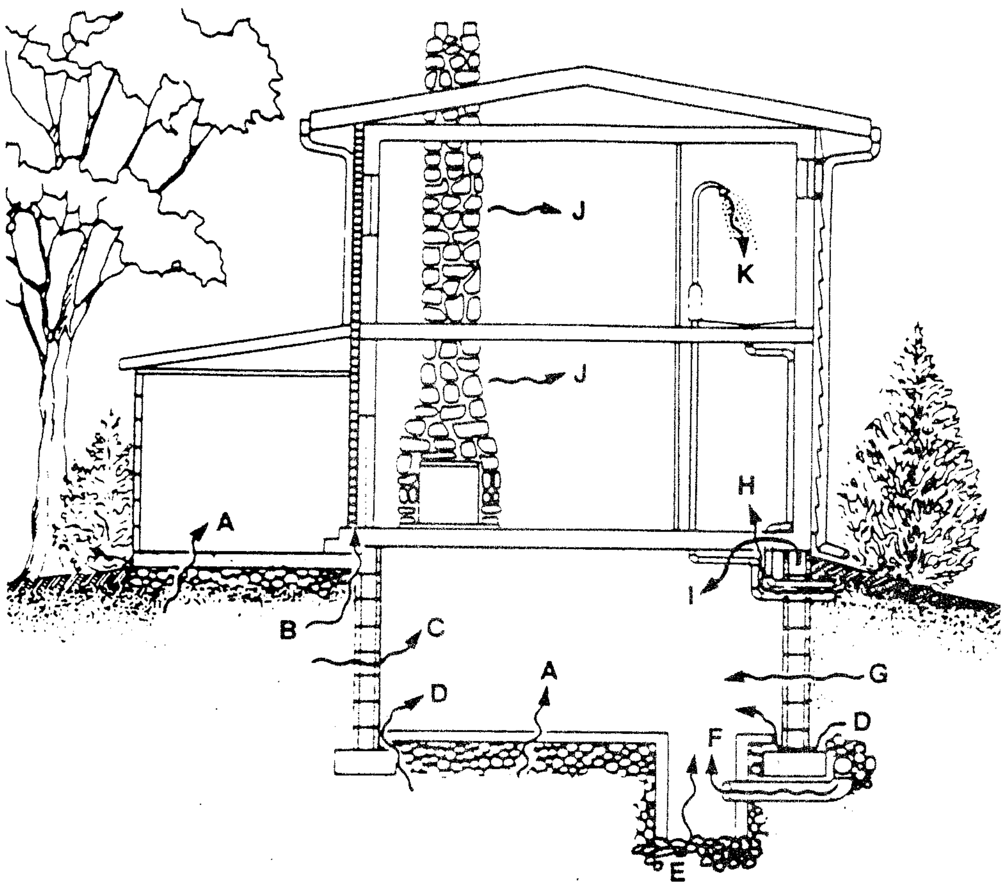
8. Given the information that you have collected in this exercise, do you think that radon is a problem in your home? What information are you lacking that you would need to make a reasonable evaluation? How could you obtain the needed additional information?



A. Cracks in concrete slabs
B. Spaces behind brick veneer walls that rest on hollow-block foundation
C. Pores and cracks in concrete blocks
D. Floor-wall joints
E. Exposed soil, as in a sump
F. Weeping (drain) tile, if drained to open sump
G. Mortar joints
H. Loose fitting pipe penetrations
I. Open tops of block walls
J. Building materials such as some rock
K. Water (from some wells)

Figure 1. Possible routes of radon entry from soil into a typical home.

TEACHER'S NOTES 7

HOW CAN YOU CONTROL RADON IN YOUR HOME?

BACKGROUND

This lesson plan on radon mitigation is open-ended. The primary objective is to allow students to utilize whatever knowledge they have about housing design and construction, and to come up with some creative and workable solutions to a radon problem. This exercise might best be conducted in small groups of 3 to 5 students.

The mitigation strategies designed by the students should take into consideration the principal entry routes of radon into a house and normal air flow patterns. Radon enters via openings in the lower portions of the home: small cracks in the slab or foundation, through the tops of hollow cinder-block walls, at the joints where walls and floors come together, and through holes that allow the passage of water or sewer lines or electrical conduits. Remember that the ultimate source of the radon is the rocks and soils under the house.

Hot air rises. Heat and air escape largely through the upper portions of the house, especially on the leeward side (away from the prevailing wind). This escape of air at the top of the house causes the creation of a slight vacuum in the lower sections of the house. Air will be pulled in via the pathways of least resistance. These can be open windows or some of the openings to the soil through which radon is pulled by the suction of the vacuum.

Mitigation strategies for elevated radon are selected on the basis of:

- how high the radon concentrations are
- house design
- appearance (aesthetics) of the remedies
- cost/benefit trade-offs
- difficulty of implementation.

Some common mitigation strategies include one or more of the following:

1. Natural ventilation - opening windows and vents to facilitate the flow of outside air into the house, especially on the lower levels.

2. Forced ventilation - installation of one or more fans to blow air into (never out of) the house on the lower levels. Blowing air out of the house can make the problem worse by increasing the vacuum effect that pulls radon in. Any increase in ventilation will increase the heating and cooling costs.

3. Forced ventilation with heat recovery - heat exchangers blow air both into and out of the house at the same time. The ducts are arranged in a fashion to allow the incoming air to be partially warmed or cooled by the outgoing air. These systems reduce the amount of added heating/cooling costs that result from ventilation.

4. Sealing radon gas entry points, such as:
   - floors in basements or crawl spaces
   - floor drains
   - perimeter drains around basements
   - uncapped top blocks in hollow-block walls
   - cracks and holes in foundation walls
   - joints between walls and basement floor.

5. Soil ventilation - drawing soil gas away from the house before it enters. Fans are used to put suction on the soil around and under the house to draw the air away, or to blow outdoor air into the soil. The latter creates a "pressure bubble" underneath the house that forces soil gas away from the house.

Students may come up with some of these strategies, or variations thereof, on their own. Alternatively, some groups of students may need some assistance from the teacher to get started (See Resources, Information Resources).

Note: Have students use Figure 1 in Investigation 6 (page 49) to assist them in designing mitigation strategies for their homes.

MINIMUM RECOMMENDED TIME ALLOCATION

One class period, plus a homework assignment to complete the write-up.

STUDENT RESPONSES

There are no "correct" answers for this exercise. Student responses should be well thought-out, should reflect an understanding of radon inflows and outflows from the home, and should propose reasonable and workable solutions.

INVESTIGATION 7

HOW CAN YOU CONTROL RADON IN YOUR HOME?

INTRODUCTION

Once you have obtained measurements of the average household radon concentration that you and your family are exposed to, what is your next step? At what level should you become concerned? What is a "safe" level? At this time, there appears to be no totally safe level of radon in household air. The EPA recommends 4 pCi/L as an "action level" for radon in homes. In other words, if the average concentration of radon in your home is at or above 4 pCi/L, EPA scientists think it would be prudent for you to do something about it. This action level is based on a number of criteria, including the study of cancer incidence in underground miners, laboratory animal experiments, and practicality. The "action level" of 4 pCi/L is technologically achievable. In fact, mitigation techniques are so improved that levels below 4 pCi/L are often possible, *and*, the lower the radon levels, the more your risk is reduced. Obviously, if the average concentration of radon in your home is 200 pCi/L, there is considerably more urgency to do something about the problem than if the average concentration is 5 pCi/L. There are no cut-and-dry rules; you must use some common sense. If the concentrations are 8 pCi/L in the basement and 2 pCi/L on the main floor, but nobody spends any time in the basement, there may be less cause for concern.

Mitigation is a term that is used to mean "fixing the problem." If your tests suggest that the radon levels are too high, and you want to do something about it, then the next step is to implement one or more mitigation strategies to decrease the radon concentration and thereby decrease your health risk. There are many different radon mitigation techniques, but they all involve one of two things: 1) keeping radon from leaking into the house, and 2) once radon enters the house, ventilating it out. The best approach or combination of approaches to use will depend on such things as:

- how high the test results are
- the design and air flow patterns of the house
- the cost of different strategies, including added heating or cooling costs
- appearance (i.e., exposed ventilation pipes in the basement).

Specific strategies might include sealing the cracks and openings in and around the concrete slab under the house and the foundation, increasing ventilation with fans or heat-exchangers, or drawing soil gas away from the house before it enters. Some corrective measures can be implemented by the homeowners; some require the skills of a professional radon contractor. The cost of effective mitigation may vary from $100 to a few thousand dollars. The work itself can be done by a homeowner or a professional radon contractor. Regardless of who does the work and how much it costs, confirmatory testing should always be done to see how successful the mitigation has been. **In this exercise you will design two strategies to fix the radon problem in your home based on hypothetical radon levels.**

OBJECTIVES

To analyze the benefits of different strategies to reduce radon concentrations in the home.

PROCEDURE

1. Examine your home in detail to evaluate the major sources of radon from the soil into your home. Assuming that the average radon concentration in your home was measured at 10 pCi/L, design two alternative strategies for radon mitigation in your home. Mitigation strategy # 1 should be based on the principle of preventing radon from entering the house. Mitigation strategy # 2 should be based on the principle of ventilating excess radon out of the house after it has entered.

ANALYSIS

2. Describe your two mitigation strategies.

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3. What are the advantages and disadvantages of each?

Hint: Include in your discussion an evaluation of the relative difficulty of implementing your proposed strategies, relative costs of implementation, aesthetics, and the potential ramifications regarding the energy-efficiency of your home and heating/cooling costs.

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CONCLUSIONS

4. How would your response to the problem differ if your house was measured at 5 pCi/L, as compared with 50 pCi/L?

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TEACHER'S NOTES 8

IS THERE RADON IN NEW JERSEY?

BACKGROUND

In this exercise, students will make decisions regarding how to approach the problem of identifying homes with high radon. They may have a difficult time getting started, but with some encouragement may devise some very creative solutions. This exercise is best performed in small groups of 3 to 5 students.

MINIMUM RECOMMENDED TIME ALLOCATION

One class period, followed by a homework assignment to write up the results.

STUDENT RESPONSES

Question 2: Students should be able to calculate how many measurements they will be able to make (400), and should deal with the issue of how to go about selecting which homes to measure. Because of the limited number of measurements that can be taken, they should reason that screening tests would be best designed to estimate "worst case" radon levels. Since the students are looking for the homes highest in radon, their strategy should take into account the location of homes *known* to be high and the underlying geology and soils in these areas.

Question 3: For initial tests (worst case), measurements should be taken on the lowest level of the home (basement if there is one). For measuring the average exposure of the residents, measurements should be distributed among some of the rooms where residents spend most of their time.

Question 4: Answers will vary.

Question 5: Answers will vary.

INVESTIGATION 8

IS THERE RADON IN NEW JERSEY?

INTRODUCTION

It is difficult to predict where radon is apt to accumulate to high concentrations in indoor air and thus constitute a potential health problem. Scientists at the U.S. Environmental Protection Agency (EPA) have attempted to do just that by constructing a map of the United States that shows areas with "potentially high radon levels" (Figure 1). It was based on geologic data and indicates those areas where there are known deposits of granite, phosphate, shale, and uranium - all likely sources of radon. EPA scientists are not satisfied that the map represents an accurate picture of radon concentration, and caution that it should not be used for predicting high radon levels in individual homes. If you live in one of the darkened areas, you don't necessarily have a radon problem. Similarly, if you live outside the darkened areas, you could still have high radon levels in your home. There is no way to predict for individual homes. No one should use his or her neighbor's test results as an indicator of his or her own radon levels.

Areas of high radon levels have been found in just about every state, and new areas of contamination are being discovered as more people test their homes. Testing of homes has not been uniform in all states. Several states, including Pennsylvania, Washington, and New Jersey, have revealed more than 1000 homes with radon concentrations higher than EPA's "action level"[1].

Geographers and geologists have divided the State of New Jersey into a number of discrete units, called physiographic provinces, based largely on the processes responsible for the formation of rocks and land features in the region (Figure 2). Granite rocks in the Highlands area, also called the Reading Prong, are very old (almost one billion years), and contain high concentrations of uranium. Rocks in the Piedmont area are younger (less than 1/4 billion years) and include shale and other sedimentary rocks that are high in uranium. The Valley and Ridge Province also contains high quantities of uranium, although glacial debris tends to be very thick, which prevents radon gas from reaching the surface prior to its breakdown into a non-gaseous element.

> Because of the uncertainties in identifying areas of high radon and the difficulties in predicting the location of individual homes with elevated levels of radon, the New Jersey Department of Environmental Protection and Energy (DEPE) recommends that *all* homes in the state be tested for radon.

Radon is a geologic phenomenon and houses that accumulate very high concentrations of radon tend to occur in clusters. If a house is identified with high radon concentrations, there is a good chance that other houses within a one mile radius may also have elevated radon concentrations. The DEPE has found that when a house has radon levels of 200 pCi/L or more, 75% of the surrounding homes (within a one mile radius) will have radon levels at or above 4 pCi/L. **In this exercise you will explore the geographic aspects of radon in New Jersey.**

[1]EPA's action level (4 pCi/L) is the level above which EPA recommends that some remedial action be taken.

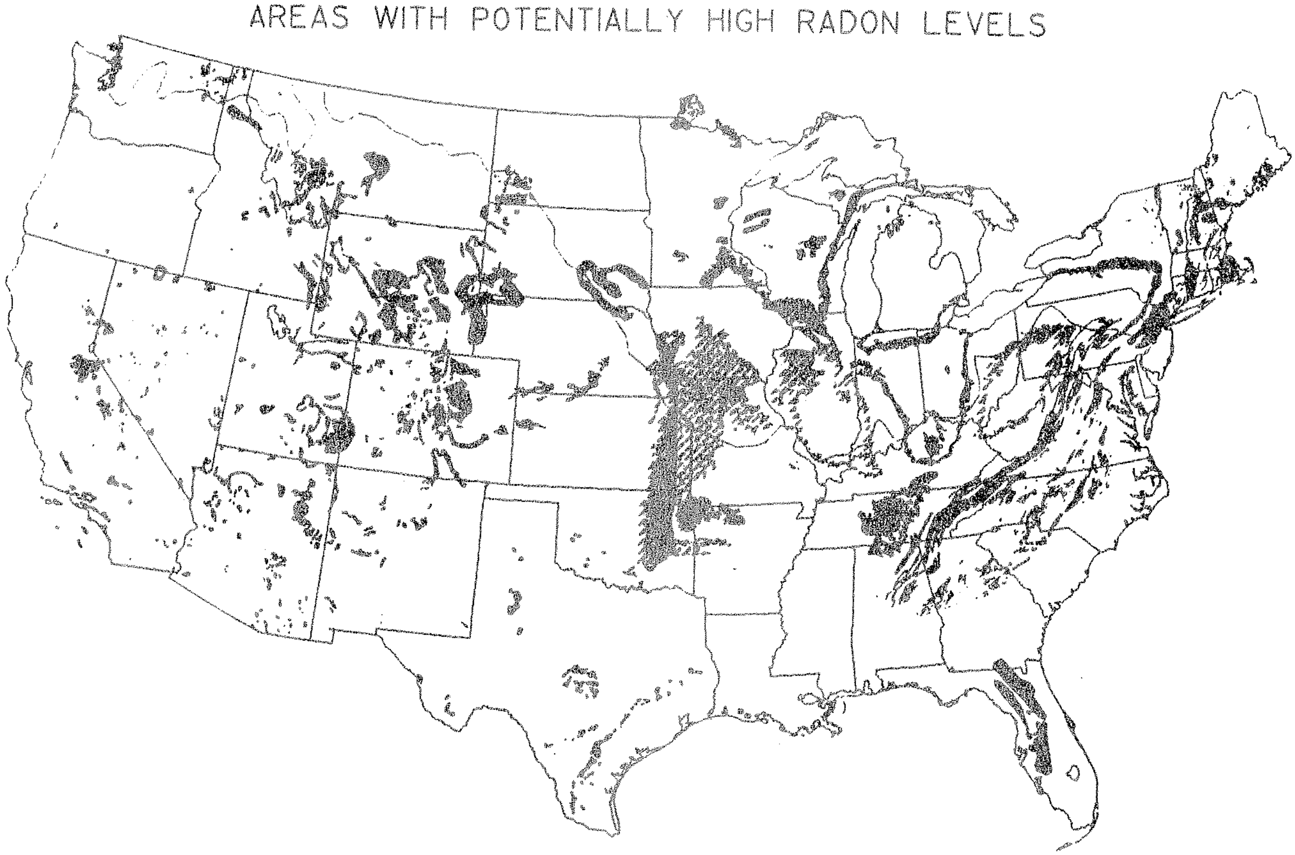

Figure 1. Major areas of the United States that have "potentially high concentrations of radon" in indoor air. This map was constructed by the U.S. Environmental Protection Agency from geologic information on the distribution of certain rock types known to be associated with radon release.

OBJECTIVE

To explore the geographical aspects of the radon issue in New Jersey.

PROCEDURE

1. Review the maps in Figures 1 and 2, and the inset boxes on the Watras story and the Clinton story.

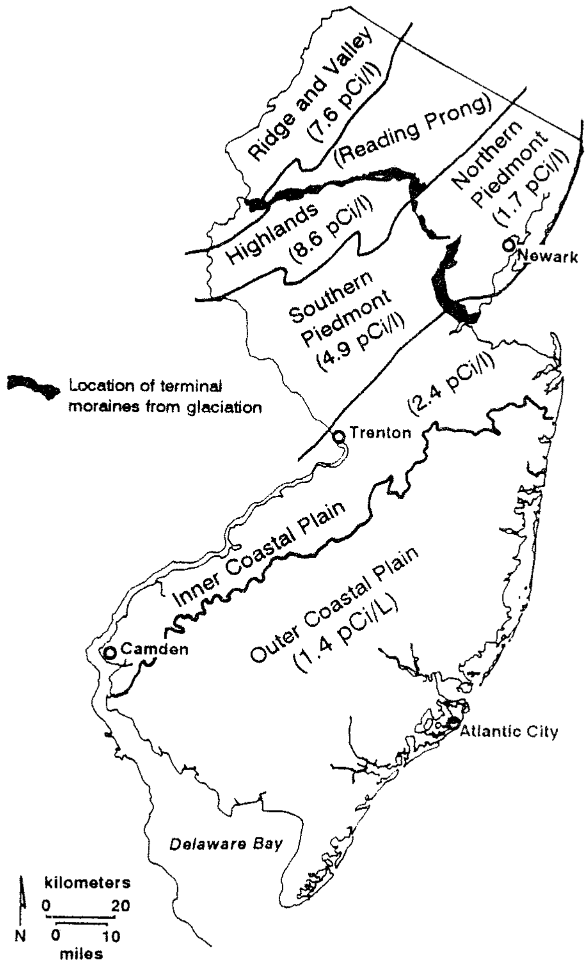

Figure 2. Physiographic provinces of New Jersey and the average concentration of radon measured in homes in each province. The highest concentrations of radon in the state have been found in homes located in the Highlands, Valley and Ridge, and southern Piedmont areas.

The Watras Story

Radon was generally unknown to most citizens of New Jersey 10 years ago. The event that triggered the widespread publicity that radon has received in recent years occurred across the border in Pennsylvania in 1984. Stanley Watras worked at that time at the Limerick Nuclear Power Plant in Pottstown, near Reading. A monitor was installed at the plant to check workers to make sure they did not accidently accumulate an unsafe dose of radiation at work. Watras repeatedly triggered the alarms on the detector going into work, and spent hours in decontamination rooms trying to get rid of the radiation on his clothes and body. Eventually,he discovered that he was not picking up the radiation at work, but rather was bringing it to work from home!

A team of specialists was sent to the Watras home to investigate. There they measured radiation levels about 700 times higher than the maximum level considered safe for human exposure. The source of this enormous amount of radiation turned out to be radon, a naturally-occurring gas that made its way into the Watras home from underground. It had nothing to do with Watras' job. The entire family was living in an environment roughly equivalent to smoking a couple of hundred packs of cigarettes per day. They moved out of the house immediately, while the problem was being fixed.

Further study revealed a vein of uranium ore directly under the house. It was continually releasing radon gas directly into the house, thereby producing the most radioactive home anyone had ever seen. After about $30,000 worth of clean-up and construction work that involved sealing off the house from the underlying bedrock, radon levels in the Watras home were reduced to reasonable levels. Although the Watras home is undoubtedly an extreme case, there may be millions of other homes in the United States that also contain high levels of radon.

The Clinton Story

Dozens of families in a Clinton, New Jersey neighborhood learned in the spring of 1986 that their homes were contaminated with the naturally occurring radioactive gas called radon, in some cases with remarkably high levels. The findings stunned state and federal researchers, who until then had never encountered a cluster of homes with such high levels of radon, which researchers say causes lung cancer. In the months that followed, the Clinton Knoll neighborhood was turned topsy-turvy by fear of radon, and by an onslaught of environmental scientists and reporters. The neighborhood became a laboratory of sorts, with the homes used as models that became the basis of federal research on construction techniques to purge contaminated homes of radon.

Clinton Mayor Robert Nulman recalls that particular spring when he steered his community through the scare of 1986. Nulman almost proudly tells you he had a radon problem, if only to emphasize how he got rid of it and to show that radon did not deflate the value of his house. When he purchased the house it registered a level of 130 picocuries (a measurement of radiation per liter of air). The federal government recommends remedial action be taken when the level goes beyond 4 picocuries per liter. Nulman said that after a $900 system of plastic piping and a fan were installed in the basement by a contractor, at the seller's expense, the radon level dropped to below .2 picocuries per liter.

Clinton resident Robert Timko remembers the initial fear of radon he and his neighbors experienced. He said they worried about their health and the health of their children, and about the value of their properties. "The worst part was the fear, the word 'cancer'. I still occasionally think about it, but it's not in my mind all the time," Timko said. Timko had initial readings of 690 picocuries per liter in his basement and 127 in his family room. After a contractor installed remediation equipment, the levels dropped to 3.1 picocuries per liter in the basement and 1.2 in the living area.

ANALYSIS AND CONCLUSIONS

2. You have been appointed the new acting director of the New Jersey Radon Program. Your immediate priority is to identify as many homes as possible that contain more than 20 pCi/L of radon. Your budget for this task is $200,000, and you estimate it will cost about $500 per house to obtain the desired radon measurements. Using the map in Figure 2, design and describe your strategy for tackling this problem.

Hint: You have access to all existing data on radon measurements taken so far, and soils and geology maps for New Jersey.

3. Based on data collected in New Jersey so far, about twice as many homes have radon concentrations greater than EPA's action level of 4 pCi/L if you use data collected in basements as compared to the ground floors. Why do you think this occurs?

How will you take this knowledge into consideration in designing your sampling strategy for identifying homes with very high radon levels?

4. What is the best way to show the results of radon surveys so that people can understand the sampling data?

5. What kinds of data would you like to have mapped in order to help you design your strategy for Step 2?

TEACHER'S NOTES 9

WHAT ARE THE ETHICAL AND LEGAL ASPECTS OF RADON?

BACKGROUND

This exercise is intended to be open-ended and allows students to explore a complex socioeconomic and environmental issue. Students should be given opportunity to speak and write about radon. Students are asked to devise new legislation regarding radon and real estate issues. The students might design this legislation in small working groups and then have a full-class debate and discussion of the pros and cons of the proposed legislation. Students can volunteer to represent the perspective of different special interest groups (e.g., consumer safety advocates, builders, realtors, regional economic developers, regulatory agencies, children's rights advocates, etc.).

MINIMUM RECOMMENDED TIME ALLOCATION

Two class periods.

STUDENT RESPONSES

There are no "correct" responses to this exercise.

EXTENDED ACTIVITIES

1. Have students research *existing* state laws in New Jersey concerning radon, but not until after they have designed their own legislation. Compare the existing laws with those that the students propose.

2. Invite a local official to discuss with the class the process by which local ordinances and/or state legislation are drafted, revised, and made into law. See Resources, Information Resources.

INVESTIGATION 9

WHAT ARE THE ETHICAL AND LEGAL ASPECTS OF RADON?

INTRODUCTION

Radon in the environment is an important issue for geologists, radiation scientists, and health workers. But radon concerns extend into many other areas of your life in ways that are complex and far-reaching. For example, the financial consequences of finding high concentrations of radon in a house can be considerable. Mitigation costs are generally not more than a few hundred to a few thousand dollars, but a well-publicized house with high radon levels can be perceived as a major problem which affects property values throughout the neighborhood, even for nearby homes that do not have problems. A neighborhood's radon reputation has the potential to attract or discourage potential home buyers. What is the legal and moral responsibility of the owner of a rental property if he/she knows that it contains high radon? What are the responsibilities of the realtors involved in the sale of homes? Does a seller have a moral responsibility to inform potential buyers of known radon concentrations in the home? Should the results of radon measurements be confidential? **In this exercise you will draft new legislation relating to the radon issue.**

OBJECTIVE

To explore the legal and ethical issues of radon contamination and to construct statewide legislation to deal with these issues.

PROCEDURE

1. Your class has been elected to the New Jersey Legislature. The first item on the agenda this year is to remedy the lack of effective legal statutes to deal with mounting citizen complaints regarding radon problems in homes throughout the state. Draft new legislation to cover the rights and responsibilities of all parties involved in real estate transactions and rentals with respect to health threats from radon. Ensure that your new legislation shall promote fairness and protection of basic human rights, while being careful to not add unneccesarily complex bureaucracy to the system.

ANALYSIS AND CONCLUSIONS

2. Describe in detail your proposed legislation (use additional sheets of paper, as necessary).

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3. Write down the names of special interest groups that might have concerns about laws that you enact with regard to radon.

4. Write a paragraph stating what you think will be the major concerns each group will have about radon legislation. What would each group not want to see in the laws?

5. Select class members to represent special interest groups, and conduct a legislative debate on the pros and cons of the proposed legislation.

TEACHER'S NOTES 10

HOW DOES RADIATION AFFECT YOU?

BACKGROUND

An underlying objective of this exercise is to help students develop a general understanding of, and appreciation for, radiation, including its ubiquity, its uses, and misuses. Many people display an irrational fear of radiation. Hopefully, this fear can be replaced with some degree of understanding. Radiation is natural in the environment but that fact does not diminish the effects on human bodies. Human activities also contribute to radiation; e.g., x-rays, bomb testing, nuclear reactor accidents, and industrial radioisotopes. Radiation can save lives and can be used to improve our standard of living.

MINIMUM RECOMMENDED TIME ALLOCATION

One class period

STUDENT RESPONSES

Students should find that radon is generally more significant than any other radiation exposure. Medical exposure can be significant in a limited number of cases. Power plant and weapons fallout exposures are insignificant (unless a large scale accident occurs).

EXTENDED ACTIVITIES

Have students try this problem: You are digging in your garden and find what appears to be a very old bone from a large animal.. Your uncle just happens to work in a radiation laboratory. He analyzes the carbon content of the bone for you and says that the ratio of C-14 to C-12 in the bone is about 1/4 that in the atmosphere. How old is the bone?

Note: The ratio of carbon-14 to carbon-12 in a living plant or animal is always about the same as the ratio of C-14 to C-12 in the atmosphere, because carbon is constantly being taken up and given off by all living things. C-12 is stable (non-radioactive). C-14 is radioactive and decays to form nitrogen-14 with a half-life of 5700 years. When the animal or plant dies, the C-14 in it gradually starts to decay into nitrogen.

INVESTIGATION 10

HOW DOES RADIATION AFFECT YOU?

INTRODUCTION

When people hear the word *radiation*, they think of nuclear war, cancer, genetic mutations, and environmental destruction. Radiation is perceived as something to be feared. It is unfortunate that important decisions in our society can be based on these perceptions, rather than on knowledge and understanding of radiation.

The long-standing connection between nuclear weapons, peaceful uses of nuclear energy, and natural sources of radiation complicate the public perception of the risks associated with radiation. Many believe that the existence of nuclear weapons poses an enormous threat to world peace and to mankind's very existence; others feel very strongly that nuclear weapons have served as a major deterrent to war. Some people accept the use of nuclear energy only if the nuclear power plant and the nuclear waste disposal site are located in someone else's town, preferably in someone else's state. Regardless, radioactive materials have come to play an increasingly important role in our society. Much research work depends on the availability of nuclear reactors and particle accelerators. Radioactive isotopes are routinely used in thousands of ways to improve the quality of our lives and for scientific research. Important uses include areas of medical diagnosis and treatment, agriculture, geology, environmental science, and biochemistry, to name a few.

Much of the utility of radioactive isotopes is attributable to the fact that they have the same chemical properties as the stable isotopes of the same element. For example, a plant can be fertilized with a radioactive isotope of phosphorus, and a Geiger counter or other radiation detector can be used to tell how much phosphorus is taken up through the roots by a particular plant, how fast it is taken up, and where it goes within the plant. Radioactive isotopes that emit gamma radiation can be used to kill bacteria, sterilize food, or treat cancers. The ratio of uranium-238 to lead-206 can be used to estimate the age of any uranium-bearing rock or mineral. Such measurements have resulted in estimates of about 4 billion years for the age of many rocks. Since the earth must be at least as old as the rocks and minerals that make up the earth, geologists tell us that the earth must be at least 4 billion years old. **In this exercise you will evaluate your personal radiation exposure over a typical year.**

OBJECTIVE

To evaluate your personal radiation dose and discriminate among the major sources of radiation exposure to the general public.

PROCEDURE

1. Complete the "Personal Radiation Chart" to estimate your annual dose of radiation from natural and man-made sources. Compare your dose with those of your classmates. Construct a frequency distribution (e.g. bar diagram) that shows the estimated annual radiation doses for all of the students in your class. If available, you may use the LabQuest Spreadsheet and Graph to examine the frequency distribution of annual doses for the students in your class.

ANALYSIS

2. What factors (individual radiation sources) are responsible for placing some students at the upper end of the distribution?

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CONCLUSIONS

3. How significant is radon as a natural source of radiation?

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Personal Radiation Chart (modified from Brookins 1990)

Source	Radiation Dose (mrem/yr)[1]
Cosmic radiation at sea level Add 1 mrem/yr for each 100 feet that you live above sea level in addition to the base figure of 28.	28 ______
Food and beverages	28
Medical x-rays Add 40 mrem/yr for each chest or body x-ray; add 14 mrem/yr for each dental x-ray received during the past year.	______
Building materials Add 100 mrem/yr if your home is brick or cement; add 5 mrem/yr if your home is wood.	______
Ground radiation	26
Nuclear weapons fallout	4
Airline travel Add 1 mrem/yr for each 1500 miles flown in a commercial jet during the past year.	______
Power plant Add 0.3 mrem/yr if you live within 5 miles of a nuclear or coal power plant.	______
Color TV Add 1-2 mrem/yr depending on how much you watch (approximately 0.1 mrem/yr for each hour of TV watched each week).	______
Luminous watch dial Add 3 mrem/yr if you wear one.	______
Indoor radon Add 100 mrem/yr for each pCi/L of radon in your household air. If your home has not been measured, use the national average of 1.5 pCi/L.	______
Your Total Annual Radiation Dose	______

[1]Radiation dose can be measured in several ways. The unit called millirem per year (mrem/yr) is one commonly used unit of measurement.

V. ASSESSMENT

Classroom teachers are encouraged to generate their own open-ended questions as a way of measuring students' understanding of the concepts presented. Open-ended questions have the following characteristics: (a) allow for experimental design or use of data, (b) encourage personal involvement or opinion, (c) encourage multi-level responses, (d) require the integration of past knowledge and skills, and (e) have basic science/societal implications. Provided below are some sample open-ended questions.

Radioactivity

1. If you had to carry an alpha-emitting radioactive nuclide to school, would it be safer to carry it in your hand, in your shirt pocket, or in a peanut butter jar? Would it make any difference? Why or why not?

Note to Teachers:

The students should be able to answer that an alpha emitter is not dangerous *outside the body* because alpha particles do not penetrate the skin. Some students may also reason that there is danger in the possibility of accidently inhaling or ingesting some of the radioactive material if it is not kept contained.

Measurement

2. Why is it important to take careful note of the length of time that a radon detector(charcoal canister, electret, or alpha-track) is left open in the home?

Note to Teachers:

A detector measures the number of radioactive disintegrations that take place. Whether this number of disintegrations occurred during a period of 5 minutes, 5 days, or 5 months makes a great deal of difference. The data are totally useless unless you know how long the detector was deployed.

Risk Communication

3. Based on data provided by the New Jersey Departments of Health and Environmental Protection and Energy and the U.S. Environmental Protection Agency, yearly deaths in New Jersey attributable to various causes could be presented approximately as follows. Some of these are estimates and some are reported real data.

Contaminants in drinking water - 10	Other accidents - 1300
Fires in homes and public buildings - 140	Homicide - 480
Home accidents - 460	Lung and other respiratory cancers - 4,400
Exposure to radon in indoor air - 500	Total cancer deaths - 17,000
Auto accidents - 1000	Heart disease - 27,000
Total deaths from all causes - 73,000	

Construct a bar chart to display these data. You can use the LabQuest Spreadsheet, as described in Appendix A. Assume that it is your responsibility to educate the public in New Jersey about health concerns and to eliminate as many as possible of the "preventable" deaths in New Jersey. You are given an annual budget of two million dollars. How are you going to spend it?

Risk Assessment

4. You are looking at two houses trying to consider which is the best buy. After carefully examining each one you arrive at the following advantages and disadvantages for House A and House B:

House A		House B	
Advantages	Disadvantages	Advantages	Disadvantages
Less expensive than House B	Located underneath a high voltage line	Located in an upscale area	More expensive than House A
Initial radon testing shows radon level in bedroom at less than 2pCi/L	Homes in area have depreciated at a rate of 5% during the past two years	Homes in area have appreciated at a rate of 5% during the past 5 years	Has some cracks in the basement slab floor
			Home is 50 years old
Brand new house	Located near an old landfill	Well insulated	About 30 miles from school, work, and shopping area
Close to school, work, and shopping area		In walking distance to a beautiful lake	Initial radon testing shows radon level in bedroom at 8 pCi/L

Explain which home you would buy and why?

Health

5. If the energy given off by the nuclear disintegration of U-238 was about the same as the energy given off by polonium-218 (and thus the biological damage would be about the same), would you be better off inhaling the uranium or an equal amount of the polonium? Why?

Radon Sources and Variability

6. If equal amounts of radium-226, radon-222, and polonium-218 were found in the air spaces in the soil under your house, which of the three would pose a more *immediate* threat to people living in the house? Why?

7. A neighbor told you that he had tested his home for radon and the result came back with a radon level of 6 pCi/L. His neighbor (two doors down from you) also had a radon test done, and the result was 1 pCi/L. Being interested, you had your home tested and you also convinced your teacher to test your science classroom. The result from your home was 3 pCi/L and the classroom was 20 pCi/L. All the homes are within a block of each other and the school is across the street. How can you explain the different results? What does it mean in terms of your health and the health of your neighbors?

Risk Evaluation

8. The chart below shows a comparison of lung cancer risks with different concentrations of radon. The word "normal" refers to the national average of lung cancer among non-smokers.

Concentration pCi/L	Risk of Death from Lung Cancer
2000	more than 75 times normal
200	75 times normal
40	30 times normal
20	15 times normal
4	3 times normal

Explain what the chart means to you.

Scoring Guide

Open-ended questions can be scored in the following manner:

Grade	Criteria
A	Three or more concepts presented Each concept is interrelated to one another Evidence has been cited
B	Three or more concepts presented The interrelatedness of concepts is less clear Evidence has been cited
C	Some concepts presented No interrelatedness Weak evidence
D	Misconceptions, but inclusion of appropriate words and vocabulary No interrelatedness No evidence
F	Total nonsense response No interrelatedness No evidence

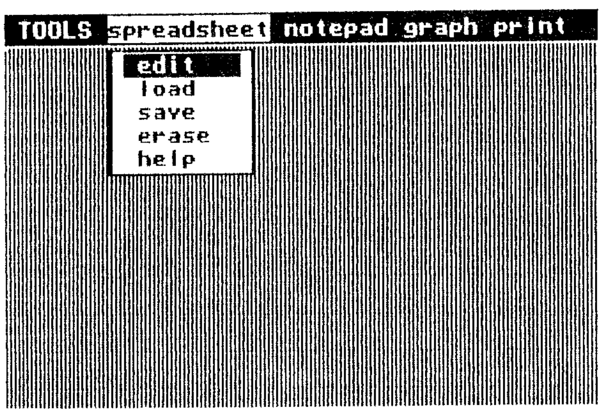
VI. APPENDICES

APPENDIX A

LabQuest SOFTWARE INSTRUCTIONS - TOOLS

SPREADSHEET

The LabQuest **Spreadsheet** includes a maximum of 910 cells (14 columns by 65 rows) on a graphics screen. The student may access the **Spreadsheet** commands by pressing Open Apple-A.



Start-up

Choose **Spreadsheet** from the Tools menu. Next, select *Edit* to create a new spreadsheet or to edit an existing one. The *Load* option will load a spreadsheet file from the disk; the *Save* option will save a spread sheet file to the disk. The *Erase* option will erase a spreadsheet from the disk. The *Help* option will review each of the **Spreadsheet** options

Sample Spreadsheet Commands

Move

1. Press Open Apple-A to see all of the possible **Spreadsheet** commands.
2. Select *Move*, and then press RETURN.
3. Choose *Block* to "block" the desired columns/rows, and then press RETURN.
4. Move the cursor to the starting position, and then press RETURN.
5. Use the arrow keys to "block" the data that you want moved, and then press RETURN.
6. Select *Relative* or *Absolute* from the Cell Number menu, and then press RETURN.
7. Move the cursor to the desired new location, and then press RETURN. The data will automatically be placed in the new location.

Functions

1. Press Open Apple-A to see all of the possible **Spreadsheet** commands.
2. Select *Functions*, and then press RETURN.
3. Move the cursor to the starting position, and then press RETURN.
4. Use the arrow keys to "block" the values that you want captured, and then press RETURN.
5. Select *Mean* from the Functions menu, and then press RETURN.
6. Move the cursor to the location where you want to display the mean, and then press RETURN. The mean will automatically be displayed in the cell.

Spreadsheet Commands

Function	Display	Student Needs
All Commands	-A	To display and access any one of 17 spreadsheet commands.
Move	-M	To move data by column, row, or block.
Copy	-C	To copy data by column, row, or block.
Blank	-B	To erase data by column, row, block, or erase all data.
Format	-F	To adjust the alignment of labels (letters) or adjust the decimal point for values (numbers).
Sequence	-S	To set up a sequence pattern (e.g., 1,3,5,7) by column, row, or block.
Functions	-X	To display the sum, mean, median, mode, minimum, maximum, range, variance, standard deviation, or correlation coefficient; or to enter a formula.
Graph	-G	To display data from the spreadsheet on a line, bar, circle, scatter, x/y, stacked bar, or normal curve graph.
Insert	-I	To insert a column or row with pushover.
Delete	-D	To delete a column or row with pushover.
Edit	-E	To edit a current cell on the spreadsheet.
Recalculate	-R	To recalculate the Spreadsheet.

Function	Display	Student Needs
Load	-L	To load a spreadsheet file.
Calculator	-K	To access the Calculator.
Notepad	-N	To access the Notepad.
Printer	-P	To access the Printer Panel.
Operations	-O	To access the Operations Panel.
Help	-H	To review a short description of the Spreadsheet commands.

Note: represents open or closed apple.

Mathematical Formulas

Students can use the *Functions* option to access any one of the built-in functions such as sum, mean, median, mode, minimum, maximum, range, standard deviation, variance, and correlation coefficient. Students also can enter the built-in functions or several different mathematical formulas manually.

Statistical Functions

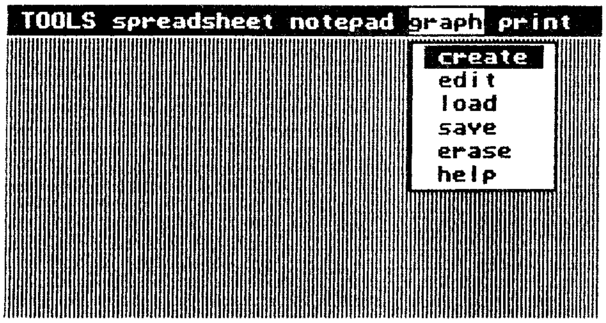
Function	Formula	Student Needs
Sum	SUM(A1:A3)	To find the sum of Cells 1, 2, and 3 from Column A.
Mean	MEAN(B4:B15)	To find the mean of Cells 4 through 15 from Column B.
Median	MDN(C1:C65)	To find the median of Cells 1 through 65 from Column C.
Mode	MODE(D1:D30)	To find the mode of Cells 1 through 30 from Column D.
Minimum	MIN(C1:C5)	To find the minimum value of Cells 1 through 5 from Column C.
Maximum	MAX(C1:C5)	To find the maximum value of Cells 1 through 5 from Column C.
Range	RNG(A1:A6)	To find the range of Cells 1 through 6 from Column A.
Variance	VAR(A1:A6)	To find the variance of Cells 1 through 6 from Column A.
Standard Deviation	SDV(D1:D35)	To find the standard deviation of Cells 1 through 35 from Column D.
Correlation Coefficient	COCO(A1:B6)	To find the correlation coefficient between Columns A and B in Rows 1 through 6.
Formula	X*1.18	To increase the value of a block of data by 18%.

Mathematical Functions

Function	Formula	Student Needs
Add	A1 + A7	To add Cell A1 and Cell A7.
Subtract	A1 - A7	To subtract Cell A1 from Cell A7.
Multiply	A1 * A7	To find the product of Cell A1 and Cell A7.
Divide	A1 / A7	To divide Cell A1 by Cell A7.
Yth Power	A1 ^ Y	To find the Yth power of Cell A1.
Yth Root	A1 ~ Y	To find the Yth root of Cell A1.
Absolute value	ABS(A1)	To find the absolute value of cell A1.
Integer	INT(A1)	To remove the fractional part of Cell A1.
Square root	SQRT(A8)	To find the square root of Cell A8.
Square	SQR(A8)	To find the square of Cell A8.
Sine	SIN(A1)	To find the sine of Cell A1.
Cosine	COS(A1)	To find the cosine of Cell A1.
Tangent	TAN(A1)	To find the tangent of Cell A1.
Arc sine	ASIN(A1)	To find the arc sine of Cell A1.
Arc cosine	ACOS(A1)	To find the arc cosine of Cell A1.
Arc tangent	ATAN(A1)	To find the arc tangent of Cell A1.
Antilog	ALOG(A1)	To find the antilog of Cell A1.
Natural log	LN(A1)	To find the natural log of Cell A1.
Logarithm	LOG(A1)	To find the logarithm (base 10) of Cell A1.
Exponential	EXP(A1)	To find the value of *e* to the A1 power.

GRAPH

The LabQuest **Graph** lets students display data from the **Spreadsheet** on a line, bar, circle, scatter, x/y, stacked bar, or a normal curve graph using a 40 column graphics screen. The **Graph** can be accessed directly from the **Spreadsheet** command menu (Open Apple-G) or from the Tools menu.

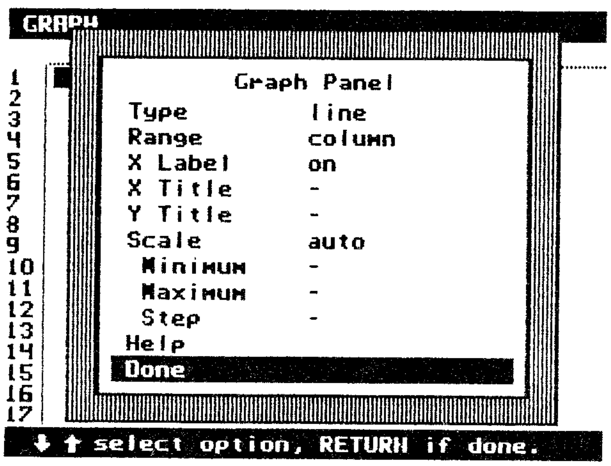


Start-up

Choose **Graph** from the Tools menu. Next, select *Create* to create a new graph or to edit an existing one. The *Load* option will load a graph file from the disk, and the *Save* option will save a graph file to the disk. The *Erase* option will erase a graph file from the disk; the *Help* option will review each of the **Graph** options.

Sample Graph Command

1. Press Open Apple-A to see all of the possible **Spreadsheet** commands, or select *Create* from the **Graph** menu.
2. Select *Graph* from the **Spreadsheet** commands, and then press RETURN.
3. Move the cursor to the starting position, and then press RETURN.
4. Use the arrow keys to "block" the desired data in Columns A and B, and then press RETURN. Toggling the Space Bar will let you skip any data range from appearing on the graph.
5. Use the arrow keys to adjust the Graph Panel. When done, press RETURN at the *Done* option to display the graph. You can use the arrow keys to edit the graph or press Open Apple-A to access the **Graph** commands.



Graph Panel

Once the student has captured the desired data from the **Spreadsheet**, the **Graph Panel** will appear on the screen. The **Graph Panel** will let the student select the *Type* of graph (line, bar, circle, scatter, x/y, stacked bar, or normal curve). The *Range* option will tell the computer if the dependent variable is represented by column(s) or row(s). For example, the computer will need ot know if Column B or Row 3 from the **Spreadsheet** is the dependent variable. The *Xlabel* will let students "toggle" the *X label* (switch it on/off). The *X title* allows students to enter the name of the X-axis; the *Y title* lets students enter the name of the Y-axis. *Scale* allows students to scale the graph manually or have the computer scale it automatically. If a student selects manual, the *minimum* and *maximum* values must be entered along with the *step* or increment amount.

Graph Commands

Function	Display	Student Needs
All Commands	-A	To display and access any one of five Graph commands.
Calculator	-K	To access the Calculator.
Printer	-P	To access the Printer Panel.
Operations	-O	To access the Operations Panel.
Help	-H	To review a short description of the Graph commands.

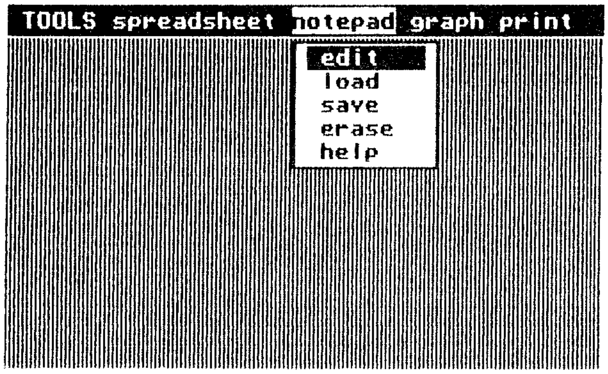
Note: represents open or closed Apple.

Graph Types

Graph	Description
Line	A line graph shows the amount of change over a period of time.
Bar	A bar graph uses bars to display data. Bar graphs are often used to represent frequencies.
Circle	A circle graph is used to show how a whole such as a pie is divided among its individual parts.
Scatter	A scatter graph is used to compare the degree of correlation between two dependent variables.
x/y	An x/y graph shows relationships and correlations between two or more variables.
Stacked bar	A stacked bar graph uses multiple-colored bars to display data and make comparisons within and between bars.
Normal curve	A standard normal curve is used to represent the distribution of standard scores.

NOTEPAD

The LabQuest **Notepad** allows students to record the results of experiments, case studies, and surveys. The **Notepad** has a maximum of 64 lines using a 40 column graphics screen. The **Notepad** can be accessed from the Tools menu or directly from the **Spreadsheet** command menu (open Apple-A).



Start-up

Choose **Notepad** from the Tools menu. Next, select *Edit* to create a new notepad or edit an existing one. The *Load* option will load a notepad file from the disk and the *Save* option will save a notepad file to the disk. The *Erase* option will erase a notepad file from the disk; the *Help* option will review each **Notepad** option.

Sample Notepad Command

Move

1. Press Open Apple-A to see all of the possible **Spreadsheet** commands or select *Edit* from the **Notepad** menu.

2. Select *Notepad* from the **Spreadsheet** commands, and then press RETURN.

3. Enter the following: "The strangest sound came from behind the closet door."

4. Press Open Apple-A and select *Move*.

5. Move the cursor to the beginning of the sentence, and then press RETURN.

6. Use the arrow keys to block the sentence, and then press RETURN.

7. Move the cursor to the desired new location, and then press RETURN. The computer will automatically place the sentence at the new location.

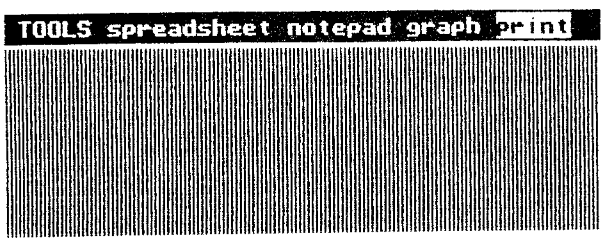
Notepad Commands

Function	Display	Student Needs
All Commands	-A	To display and access any one of eight Notepad commands.
Move	-M	To move text.
Copy	-C	To copy text.
Delete	-D	To delete text.
Printer	-P	To access the Printer Panel.
Calculator	-K	To access the Calculator.
Blank	-B	To erase all text from screen.
Show Format	-Z	To display all carriage returns.
Help	-H	To review a short description of the Notepad commands.
Delete Characters	Cont - D	To delete single characters.
Tab	Tab Key	To move five spaces forward.

Note: *represents open or closed apple.*

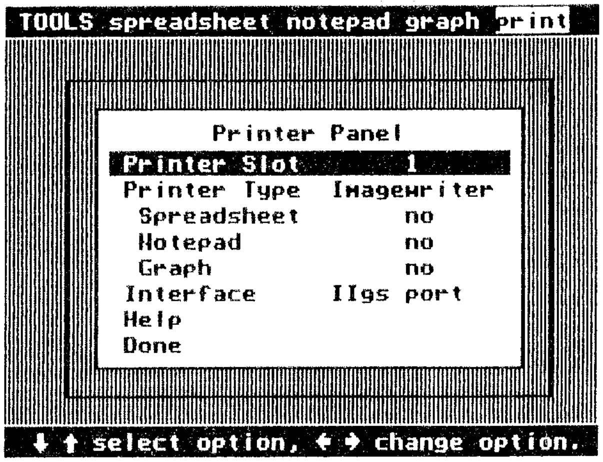
PRINT

Print allows students to print a copy of a spreadsheet, notepad, or graph at any point in the program using the Epson or Imagewriter printer. The printer interface requires a Grappler card for the Epson printer or a Super Serial Card for the Imagewriter printer.



Start-up

Choose **Print** from the Tools menu. The **Printer Panel** will be displayed on the screen. To move back to the Tools menu, press ESC.



Printer Panel

The Printer Panel allows students to determine what will be printed (e.g., spreadsheet, graph, and/or notepad) and to identify the type of printer, printer slot number, and type of interface (II GS port, IIc port or card) for the Apple computer.

Note: If using a Super Serial Card in an Apple II GS, make sure to set the slot to the appropriate type from the computer's Control Panel. See the Apple II GS owner's guide for specific instructions.

APPENDIX B

GLOSSARY OF TERMS

Action level - A guideline or recommendation established by the U.S. Environmental Protection Agency for lowering radon levels in homes in order to reduce risk; the current level is 4 pCi/L; this action level does not eliminate risk, it reduces risk.

Adsorption - Gathering or collecting on a surface; a charcoal canister works by means of adsorption.

Alpha particle - Two neutrons and two protons bound as a single, charged particle that is emitted from the nucleus of certain radioactive isotopes in the process of decay or disintegration; as radon decays it emits an alpha particle.

Alpha track detector - A long term testing device used to measure radon; it records the number of alpha particles which strike its pad during radon decay; the alpha track can be used for 3 months to a year.

Atom - The smallest component of an element, containing all the properties of the element; its structure is a center or nucleus containing protons and neutrons, and electrons orbiting the nucleus; determines the place of an element in the periodic table.

Atomic number - Represents the number of protons in the nucleus which in a neutral or stable atom equals the number of electrons orbiting the nucleus; determines the place of an element in the periodic table.

Beta particle - A charged particle emitted from a nucleus of certain radioactive isotopes in the process of decay or disintegration; the particle has the mass of an electron and (in the case of isotopes in the U-238 decay series) has a negative charge; in the uranium decay chain protactinium, lead, and bismuth isotopes emit beta particles as they disintegrate.

Cancer - An invasive growth of abnormal cells that spreads in one or more of the body's organs or systems.

Cell - A self-contained unit capable of acting alone or interacting with other cells in performing all fundamental functions of life; the least structural unit of living matter capable of functioning independently.

Charcoal canister - A short term testing device used to measure radon; it is exposed to the air for 2-7 days and works by adsorption.

Curie (Ci) - Unit of radioactive measurement, corresponding to 37 billion disintegrations per second; radon is commonly measured in picocuries (pCi) which is a trillionth of a Curie.

Daughter - See decay product.

Decay product - An isotope formed as the result of a radioactive disintegration or breakdown; also referred to as daughter product or progeny.

DNA - Deoxyribonucleic acid, found in cell nuclei and the molecular basis of heredity in many organisms; it contains the basic instruction code determining cell function and replication.

Dose - The amount of radioactive energy that a given mass or material receives and absorbs.

Electret ion chamber - A test device used to measure radon; it is exposed to the air and records the alpha particles emitted during the decay of radon; it can be used for both short and long term tests.

Gamma rays - A high energy wave emitted from the nucleus of a radioactive atom during decay or disintegration.

Half-life - The time required for a radioactive substance to lose 50% of its activity by decay; different radioactive elements have varying half-lives: uranium-238 - 4.5 billion years, lead-214 - 27 minutes, and polonium-214 - 164 microseconds; different radioactive isotopes of the same element have varying half-lives: radon-222 - 3.8 days, radon-220 - 55.6 seconds, and radon-219 - 4 seconds.

Isotopes - Nuclides having the same number of protons in their nuclei, and therefore the same atomic number, but varying in the number of neutrons, so the mass is different. Chemical properties of isotopes of a particular element are almost identical, but half-life varies; the term isotope should not be used as a synonym for "nuclide".

Lifetime risk - The risk of dying from some particular cause over the whole of a person's life.

Mass number - The combined number of protons and neutrons in the nucleus of an atom; varying number of neutrons will result in different isotopes of an element.

Mitigation - The action of correcting, countering, or treating a problem, such as elevated radon levels; synonymous with the term remediation.

Neutron - A particle of an atom contained in the nucleus; it has no charge; it is the determinant of the mass number of an element and therefore its species of isotope.

Nucleus - The central structure of an atom; it is the location of protons and neutrons; the plural is nuclei.

Nuclide - A species of atom characterized by the make up of its nucleus, the number of protons, neutrons and its energy content.

Picocurie - A measurement of radioactive disintegrations; it is one trillionth of a curie.

Progeny - See decay product.

Proton - A particle of an atom located in the nucleus; it has mass and weight, and a positive charge.

Radiation - The emission of energy in the form of particles and waves.

Radioactivity - The spontaneous emission of energy or radiation from the nucleus of certain atoms during decay; the energy is emitted or released in the form of alpha or beta particles and may also be accompanied by gamma rays.

Relative risk - Comparative hazard or danger estimated for an exposed population as opposed to a population without exposure; expressed as a ratio.

Remediation - See mitigation.

Risk estimate - The number of cases (or deaths) that are projected to occur in a specified exposed population per unit dose of a toxic or carcinogenic agent for a defined exposure route and time period.

Threshold - The level at which a response or effect is observable; currently there is no known safe threshold level for radon exposure; adverse effects have been observed at very low doses.

Uranium series - Radioactive-decay chain starting with uranium-238 and contain ing radon-222 and its decay products.

APPENDIX C

RESOURCES

1. Training/Workshops
2. State Radon Programs
3. Speakers/Field Trips
4. Equipment and Materials
5. Information and Resources
6. Illustrations and Maps
7. Additional Reading

1. Training/Workshops

LabQuest training workshops are available nationwide to provide educators with an easy-to-use and practical spreadsheet and graphing program for the Apple, IBM, and Macintosh platforms. If you are interested in participating in a LabQuest workshop, please call Dr. Bruce Marganoff, Science Specialist, New Jersey Department of Education at 609/984-1805 or Dr. Chris Moersch, Director, National Business Education Alliance at 503/753-3011 for more information.

2. State Radon Programs

Alabama: 800/582-1866
Arizona: 602/255-4845
California: 800/745-7236
Connecticut: 203/566-3122
District of Columbia: 202/727-5728

Alaska: 800/478-4845
Arkansas: 501/661-2301
Colorado: 800/846-3986
Delaware: 800/554-4636
Florida: 800/543-8279

Georgia: 800/745-0037
Idaho: 800/445-8647
Indiana: 800/272-9723
Kansas: 913/296-1560
Louisiana: 800/256-2494

Hawaii: 808/586-4700
Illinois: 800/325-1245
Iowa: 800/383-5992
Kentucky: 502/564-3700
Maine: 800/232-0842

Maryland: 800/872-3666
Michigan: 517/335-8190
Mississippi: 800/626-7739
Montana: 406/444-3671
Nevada: 702/687-5394
Massachusetts: 413/586-7525
Minnesota: 800/798-9050
Missouri: 800/669-7236
Nebraska: 800/334-9491
New Hampshire: 800/852-3345 x4674

New Jersey: 800/648-0394
New York: 800/458-1158
North Dakota: 701/221-5188
Oklahoma: 405/271-5221
Pennsylvania: 800/237-2366
New Mexico: 505/827-4300
North Carolina: 919/571-4141
Ohio: 800/523-4439
Oregon: 503/731-4014
Puerto Rico: 809/767-3563

Rhode Island: 401/277-2438
South Dakota: 605/773-3351
Texas: 512/834-6688
Vermont: 800/640-0601
Washington: 800/323-9727
Wisconsin: 608/267-4795
South Carolina: 800/768-0362
Tennessee: 800/232-1139
Utah: 801/538-6734
Virginia: 800/468-0138
West Virginia: 800/922-1255
Wyoming: 800/458-5847

3. Speakers/Field Trips

1. The American Association of Radon Scientists and Technologists (AARST) may be able to provide a speaker for your class who will talk about testing and/or mitigation. The Association's address is P.O. Box 70, Park Ridge, NJ 07656 and their phone number is 201/391-6445.

2. The following all have active educational programs which arrange for speakers and field trips. Speakers usually will come only to schools in their company's service area. Be sure to ask.

   1. Atlantic Electric - 609/645-4545

   2. GPU (Oyster Creek Nuclear Powerplant) - 609/971-4057

   3. JCP&L - 201/455-8783

   4. PSE&G - 201/430-5863
      Hope Creek Nuclear Powerplant - 609/935-2660

3. In the field of medicine, radiation has a major role in diagnosis and treatment. Many hospitals and medical centers have community affairs programs for area residents about a variety of health issues. Contact your area hospital about arranging a tour or hearing a presentation.

NOTES :

4. Equipment and Materials

M&M'S - On school letterhead, you may write to M&M/Mars requesting information about the company and a coupon towards the purchase of a bag of m&m's. Letters should be addressed to: M&M/Mars, Consumer Affairs, High Street, Hackettstown, NJ 07840.

NEW JERSEY ROAD MAPS - Contact: NJ Department of Commerce and Economic Development, 20 West State Street, CN-826, Trenton, NJ 08625 or call 609/292-2470.

RADIATION COUNTERS - These instruments (e.g., Geiger counter and micro-R meter) are useful means to demonstrate to students that although radiation cannot be seen, it is there. If you do not have access to a radiation counter, try to secure an instrument through one of the following:

1. Through your school or school district, you may want to purchase a radiation counter. Examples of companies that sell this type of equipment for schools are Edmund Scientific (609/573-6250) and Fisher Scientific/EMD (800/955-1177).

2. Speakers from the energy industry might be able to give a demonstration during a presentation. See Resources, Speakers/Field Trips.

3. In New Jersey, you may contact the state Radon Program. The Program has a limited number of micro-R meters which may be available for loan at certain times. See Resources, State Programs.

4. Some county and local health offices and some colleges have counters. You might contact health offices and colleges in your area to find out if they have such equipment and if they would be able to give a demonstration.

NOTES:

5. Information Resources

LIBRARIES - In 1986, New Jersey libraries began a network system in order to "provide...residents with full and equal access to library materials and programs not currently available within their communities". The counties were grouped into regions (total of six). Each region coordinates and oversees the provision of library services for the residents of its respective area. The entire network is overseen and funded by the New Jersey State Library. Any library can become a participant in the regional network, and many have, including a number of school libraries.

When you are researching information for these lesson plans or seeking additional reference materials, be sure to speak with your school librarian and/or the local public librarian about the New Jersey Library Network.

<u>Region 1</u> - Hunterdon, Morris, Somerset, Sussex, and Warren counties

<u>Region 2</u> - Bergen and Passaic counties

<u>Region 3</u> - Essex and Hudson counties

<u>Region 4</u> - Middlesex and Union counties

<u>Region 5</u> - Mercer, Monmouth, and Ocean counties

<u>Region 6</u> - Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, and Salem counties

ARTICLES - Most newspapers do not publish indexes of their news articles, but almost every newspaper maintains a library. Contact your local area papers and ask the librarian for assistance.

LEGISLATION - In New Jersey, the Office of Legislative Services produces a pamphlet called, ''The Legislative Process in New Jersey''. Call 1-800/792-8630 for copies.

MITIGATION/REMEDIATION - In New Jersey, only businesses certified by the state may conduct mitigation/remediation work. Contact the New Jersey Radon Program (see State Radon Programs) for a list of certified businesses. See Speakers/Field Trips regarding arranging a presentation about this topic.

PATENTS - In New Jersey, there are only two patent depository libraries; Newark Public Library and Rutgers University. Your school or local librarian should be able to help you find out the procedures for viewing patent documents.

POSTER - In New Jersey, a free copy of a radon poster/chart prepared by the US Environmental Protection Agency is available from: NJDEPE/Radon Program, ATTN: Communications/Outreach, CN-415, Trenton, NJ 08625. Please be sure to state that you want the USEPA radon poster/chart.

TESTING - In New Jersey, only businesses certified by the state may conduct testing and sell test devices. Contact the New Jersey Radon Program (see State Radon Programs) for a list of certified businesses, and only work with these businesses if you are going to do any testing.

VIDEO - Copies of a video prepared by the American Lung Association, ''Radon: The Hazard in Your Home'' have been distributed to the county AVA commissions and are available for loan. Additional copies are available from the New Jersey Radon Program (see State Radon Programs) and can be provided to a <u>school district</u> for use in its schools.

NOTES :

6. Illustrations/Maps

On the following pages are illustrations and maps provided for your use with the *Radon Alert* lesson plans and activities. You may want to use them to make overheads and/or photocopy for distribution to the students.

Additional copies of the Geologic Map of New Jersey may be purchased, at $.50/copy, from Maps and Publications, Bureau of Revenue, CN-417, Trenton, NJ 08625. Their telephone number is 609/777-1039.

7. Additional Reading

Brookins, D.G., The Indoor Radon Problem, Columbia University Press, New York, 1990.

Green, L., ''Radon: Comparing Risk'', Home Mechanix, June 1988.

Hanson, D., ''Low-level Risk May Be Underestimated'', C&E News, January 1, 1990.

Kay, J.G., Keller, G.E., & Miller, J.F. (eds), Indoor Air Pollution: Radon, Bioaerosols, and VOC's, Proceedings of the Symposium on ''Indoor Air Pollution: Its Causes, Its Measurement, and Possible Solutions'', 1989, Lewis Publishers, Chelsea, Michigan, 1991.

Klement, A.W., Jr. (ed), CRC Handbook of Environmental Radiation, CRC Press, Boca Raton, Florida, 1982.

Lao, K.Q., Controlling Indoor Radon: Measurement, Mitigation, and Prevention, Van Nostrand Reinhold, New York, 1990

National Research Council, Committee on the Biological Effects of Ionizing Radiations, Health Risks of Radon and Other Internally Deposited Alpha-emitters (BEIR IV), National Academy Press, Washington, D.C., 1988.

______, Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V), National Academy Press, Washington, D.C., 1990.

Nazaroff, W.W. and Nero, A.V., Jr. (eds), Radon and Its Decay Products in Indoor Air, Wiley-Interscience Publication, John Wiley & Sons, New York, 1988.

New Jersey Department of Environmental Protection and Energy, Radon Program, ''Information You Should Know About Radon'', July 1992.

______, ''Testing for Radon is Simple: Here's How'', 1992.

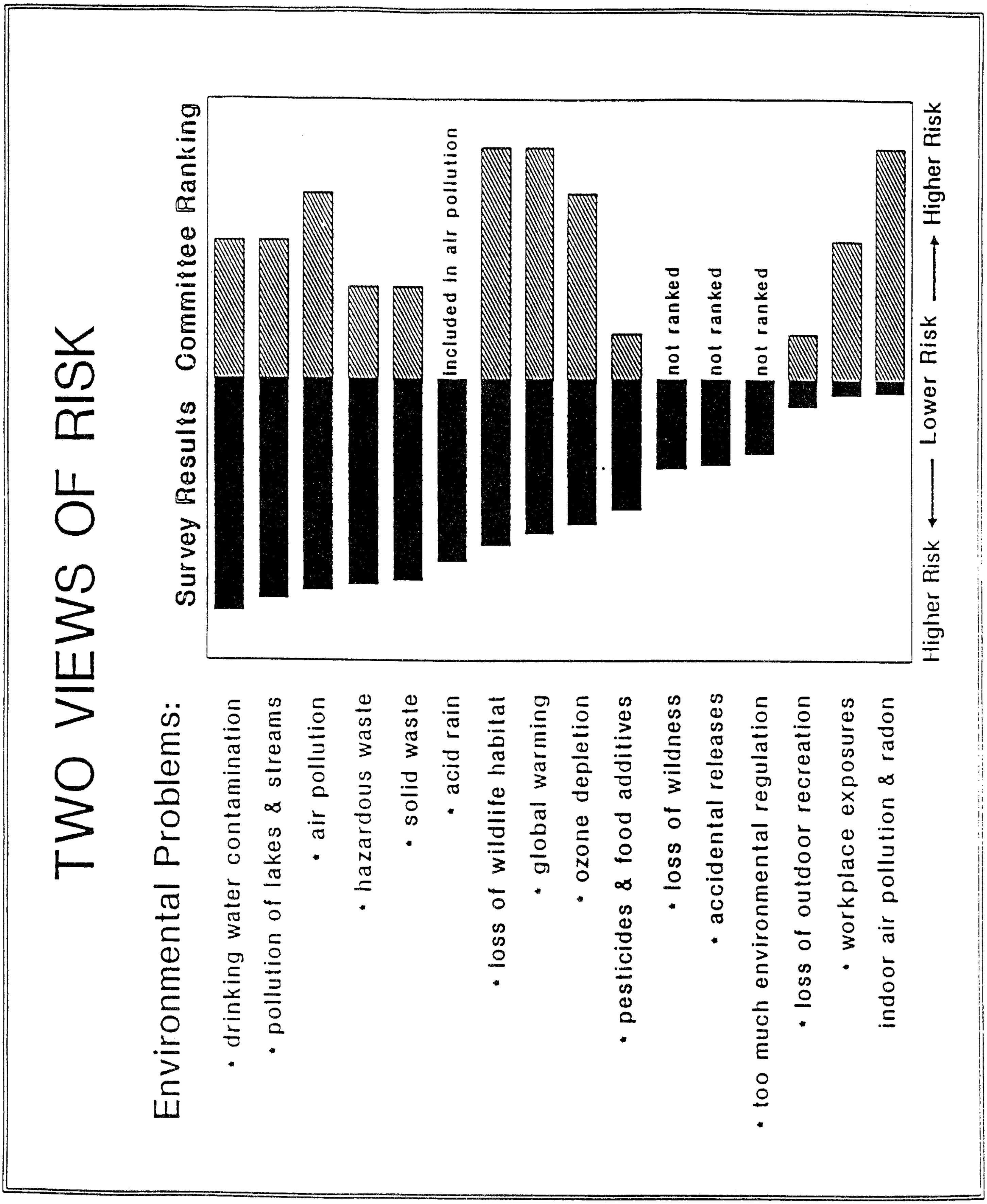
Texley, J., ''A Rational Approach to Radon'', Science Scope, January 1989.

______, ''Radon: Reducible Risks, Rational Remedies'', The Science Teacher, January 1989.

Wilkening, M., Radon in the Environment, Studies in Environmental Science; 40, Elsevier Science Publishing, New York, 1990.

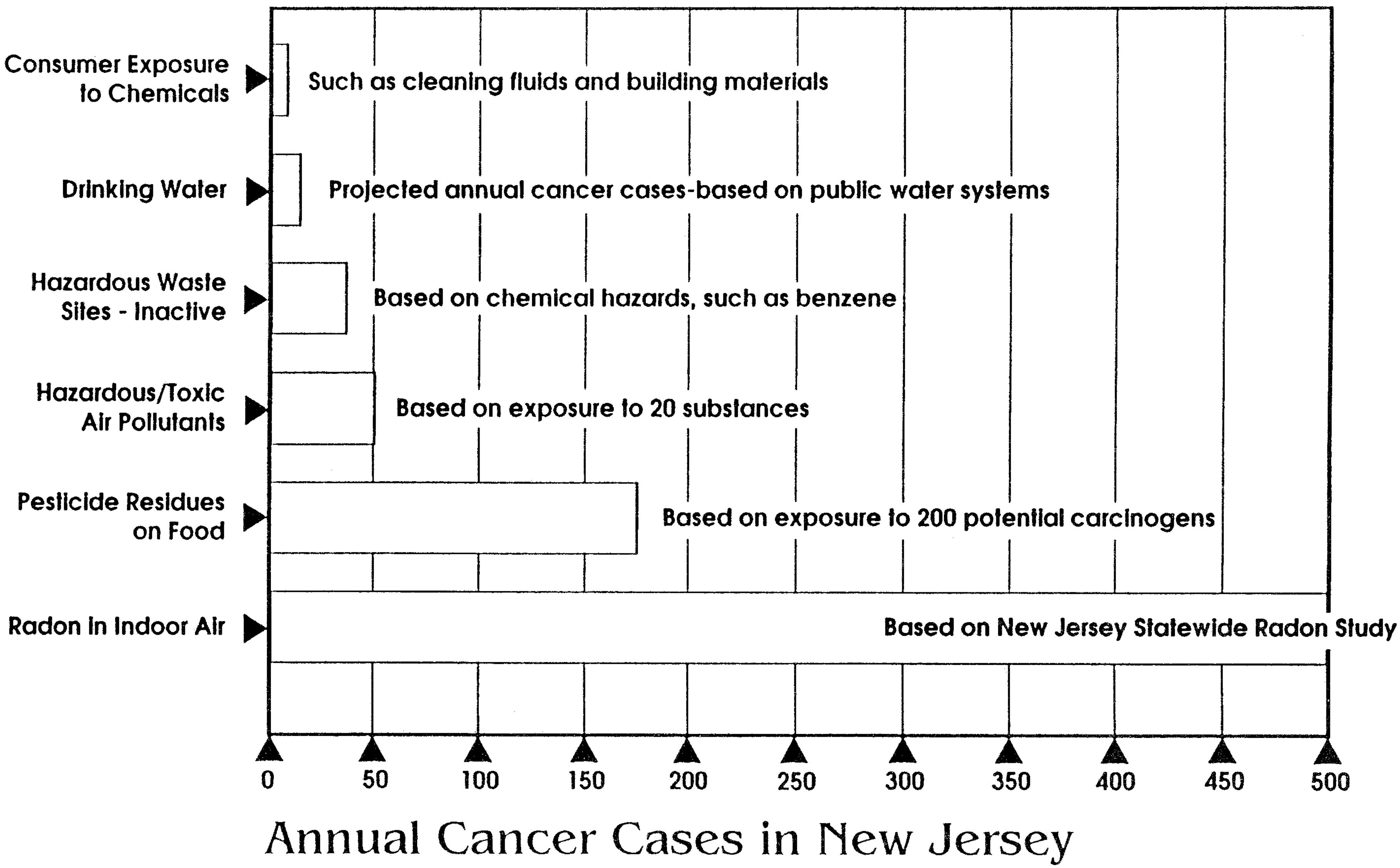
Wilson, R., ''Risk Assessments and Comparisons'', Science, April 17, 1987.

Zeckhauser, R., ''Risk Within Reason'', Science, May 4, 1990.



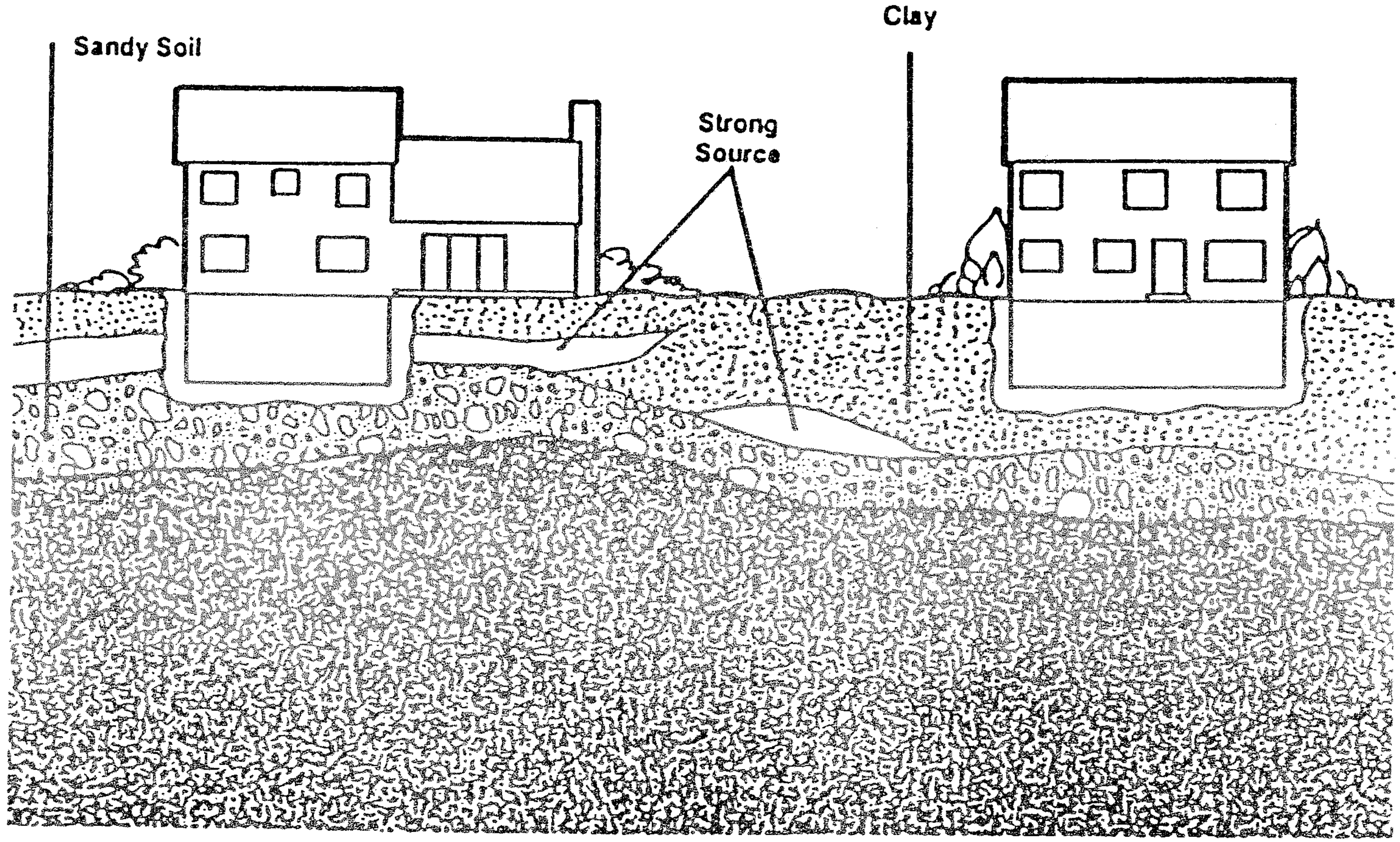
General public (survey) and "expert" (committee) views of risk associated with environmental hazards. "Environment 1991: Risk to Vermont and Vermonters", Vermont Agency of Natural Resources, Waterbury, VT, 1991.

Ranking of Environmental Problems on the Basis of Population Cancer Risk



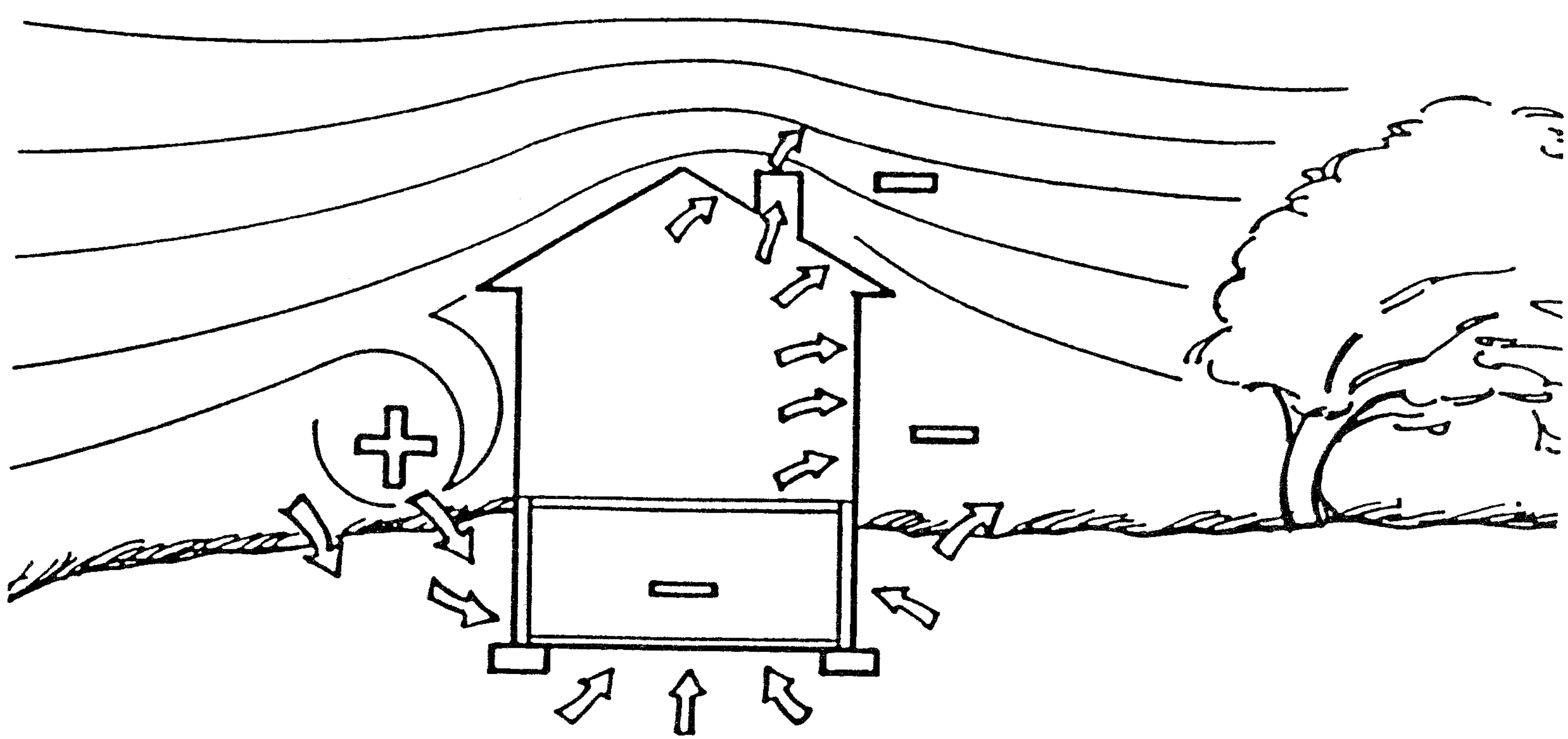
Sources: EPA - Unfinished Business: A Comparative Assessment of Environmental Problems, February, 1987, Evaluation of Carcinogenic Risk Assessments as Used by US Federal Agencies in Establishing Standards for Toxic and Hazardous Substances, July, 1985, and the NJDEPE - CDM Radon Report.

NEIGHBORING HOMES AND UNDERLYING GEOLOGY



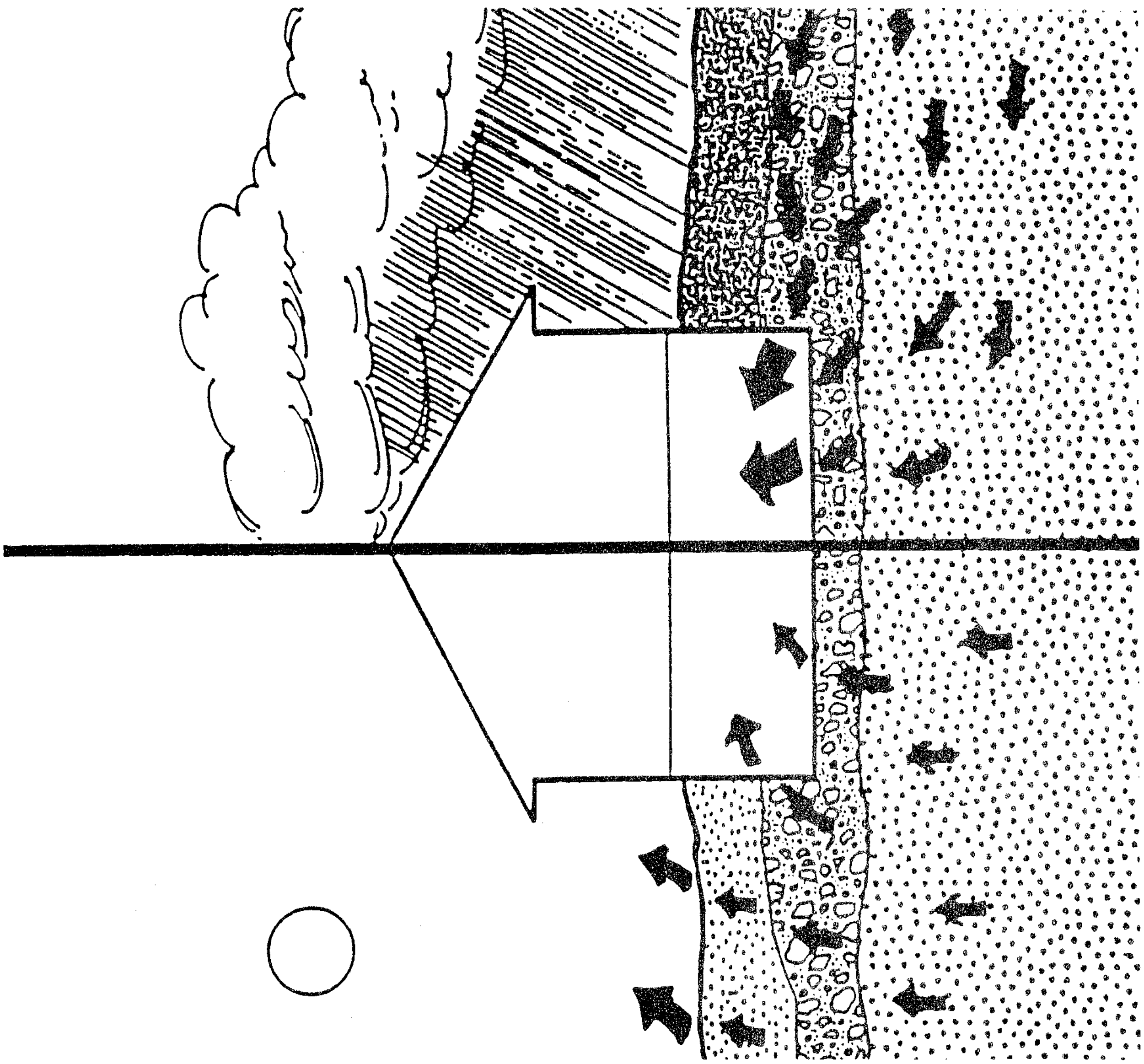
USEPA, Office of Radiation, Reducing Radon in Structures: A Manual, 2nd edition, Washington, DC, 1988/89.

WINDBLOWN EFFECT



USEPA, Office of Radiation, Reducing Radon in Structures: A Manual, 2nd edition, Washington, DC, 1988/89.

EFFECT OF RAINFALL ON RADON TRANSPORT



USEPA, Office of Radiation, <u>Reducing Radon in Structures: A Manual</u>, 2nd edition, Washington, DC, 1988/89.